Scalable Climate Solutions



Backgrounder

The Julie Ann Wrigley Global Futures Laboratory at Arizona State University and Earthshot™ will be co-hosting two meetings to convene policymakers, innovators, and the financial community to discuss accelerating scalable climate change technology solutions and policy ideas.

This *Backgrounder* describes the technologies to be discussed at the first meeting:

• Carbon sequestration in cement • Near-zero carbon cement • Enhanced structural insulated panels • Improving energy efficiency of buildings • Sealing leaks in ducts • Improving air quality and reducing HVAC loads in commercial buildings • Geothermal energy systems for homes • Electricity-producing and energy-efficient windows • Reducing methane leaks in oil and gas operations • Lightweight materials for transportation

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EARTHSHOT

Foreword

Following the Paris and Glasgow Conferences of Parties (COP), the international community and leading corporations have committed to ambitious climate targets that will require an aggressive "all of the above" approach. Success will depend in part on continued technological innovation. However, it will also require the rapid development and deployment of existing and new technologies at scale through suitable policy instruments, public and private sector investment, and consumer education and action.

By decarbonizing the electricity grid and enabling the electrification of significant portions of the transportation system, solar, wind, and battery technologies have, to date, deservedly received the lion's share of policy, media, and investor attention. Nevertheless, as important as these technologies are, they alone are not sufficient to meet our goals.

We will need many more technologies addressing a range of other sectors, including construction, building operations, agriculture, and beyond. The good news is that there are many emerging and commercially ready technologies poised to play an important role in achieving our climate goals. They meet high-performance benchmarks and can be produced and used efficiently, often at significantly lower cost than the processes and products they replace. But, like most emerging technologies, they face significant commercialization hurdles, most critically finding investors and customers. One way to help companies succeed is to help them become more visible, so investors, customers, and policy makers can see what opportunities they offer.

Earthshot's™ mission is to present a positive, cleantech-oriented vision of the future that will inspire climate action. To raise the visibility of technologies that can reduce or avoid greenhouse gas emissions, Earthshot™ will showcase their capabilities and the role they can play in solving the climate challenge. We will do that in part by developing an easily accessible website portal where all types of technologies can be presented. In addition, together with the Julie Ann Wrigley Global Futures Laboratory at Arizona State University and others, we will also sponsor periodic showcases and events to provide a public platform for companies to demonstrate what they can achieve. We are grateful to global law firm Latham & Watkins LLP, whose energy and environmental attorneys provided substantial assistance in preparing the following backgrounder to support our first cleantech showcase. This backgrounder presents examples of scalable clean technologies and highlights several companies who already are in the marketplace. Accelerating deployment of these commercially available technologies, and technologies like them, can have a powerful beneficial impact on our efforts to decarbonize the economy.

The backgrounder and the upcoming November 18 webinar represent the first part of the Earthshot™/ASU cleantech showcase. We intend to follow this event in early 2022 with a second event that highlights the many policy instruments, public and private financing and procurement opportunities, benchmarking and educational strategies, and other tools that can be used to ensure that the very best technologies are optimally deployed at a pace sufficient to achieve our climate goals.

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I. EXECUTIVE SUMMARY

New technologies have the potential to greatly reduce greenhouse gas ("GHG") emissions from the infrastructure sector, including emissions from cement manufacturing; heating and cooling of residential and commercial buildings; methane leaks in oil and gas production; and movement of people and goods in cars, trucks, and planes. This backgrounder describes these technologies and identifies companies offering them now.

We focused on the following emissions categories:

- 1 – cement/concrete manufacturing;
- 2 – heating and cooling of residential and commercial buildings;
- 3 – oil and gas production methane leaks; and
- 4 – movement of people and goods in cars, trucks, and planes.

The corresponding technologies we are highlighting to address these emissions categories are:

- 1 – Cement/concrete manufactured with lower emissions;
- 2(a) – Energy efficient building panels and windows;
- 2(b) – Solar windows which generate energy;
- 2(c) – Heating, ventilation, and air-conditioning ("HVAC") leak sealing to make the system more efficient;
- 2(d) – Reducing commercial building HVAC load through sorbent air cleaning;
- 2(e) – Smart control of commercial building HVAC systems for energy efficiency;
- 2(f) – Home geothermal energy systems;
- 3 – Fugitive emission capture systems for the oil and gas industry;
- 4(a) – Weight-related energy efficiency for cars, trucks, and planes through constructing them out of advanced materials; and
- 4(b) – Reducing emissions from goods movement by localizing manufacturing with 3D printers.

A critical consideration for Earthshot™ is to identify technologies that are commercially available now, not technologies that are being piloted or demonstrated or that are otherwise unavailable for deployment at scale. The technologies described herein, being just a few of many possible technologies we could showcase, are market-ready, economical, and can be incorporated now into new projects and retrofits (with the limited exceptions described below) to vastly reduce GHG emissions from the infrastructure sector.

Taken together, these technologies and others in these categories offer the potential for tremendous GHG emissions reductions, both in the near term and as the world's economies compete to reach net zero. Building operations and building materials alone contribute nearly 40% of global GHG emissions.[1] The GHG emissions attributable to building construction and

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[1] Architecture 2030, Why the Building Sector?, available at: https://architecture2030.org/buildings_problem_why/.

operation exceed the emissions footprint of the transportation sector, and the same is true in relation to the industrial sector. While electrifying transportation and decarbonizing the grid are critical strategies to meet emissions reduction goals, strategies to address buildings sector emissions are equally critical – but the buildings sector is often overlooked.

Cement production is the second-highest emitting industrial process in the US. Carbon dioxide is a byproduct of the calcination process that is an essential step of traditional Portland cement manufacturing (and the process requires high temperatures, which necessitates combusting fossil fuels, further contributing to GHG emissions). Carbon emissions from cement constitute approximately 8% of global carbon emissions. Technologies to reduce the carbon footprint of cement manufacturing include capturing carbon dioxide from the cement manufacturing process and embedding it in concrete, using coal fly ash as a substitute for cement when mixing concrete, and replacing Portland cement with pozzolanic cement. There now exists a pozzolanic cement process that reduces GHG emissions by more than 90% during the manufacturing process as compared to Portland cement. This pozzolanic cement provides the opportunity to radically reduce the carbon footprint of cement manufacturing. Another innovative manufacturer injects carbon dioxide ("CO_2") into concrete, which reduces the concrete's carbon footprint without compromising on performance.

The United Nations Intergovernmental Panel on Climate Change ("IPCC") has repeatedly identified buildings – which contribute 38% of energy-related global GHG emissions – as a critical field for climate action. Heating and cooling systems in particular consume large quantities of energy. Earthshot™ focuses in this report on several technologies that reduce building energy demand:

- Structural insulated panels are pre-fabricated interior and exterior construction panels with protective thermal ratings to reduce the need for heating and cooling.

- Photovoltaic windows counterbalance the loss of energy through windows via heat transfer by serving to generate their own energy.

- Tempered vacuum-insulated glass windows are specially treated advanced windows that provide low levels of thermal losses.

- Sealing HVAC systems to eliminate small leaks in heating and cooling ductwork has been demonstrated to reduce HVAC leakage rates significantly, reducing GHG emissions.

- Sorbent air cleaning technology for commercial buildings can significantly improve indoor air quality, reducing the need for energy to heat or cool outside air.

- Also in the commercial buildings sector, smart HVAC systems use sensors and controllers to capture a vast amount of data, and then analyze, predict, and control building energy usage – ensuring that HVAC systems run only when, where, and as much as is needed, to eliminate hot spots and minimize energy usage.

- Finally, in the residential space, geothermal energy systems harness subsurface energy to provide heating and cooling, allowing homeowners to stop the use of natural gas, propane, or fuel oil combustion for home heating, and to significantly reduce the energy needed for air-conditioning, avoiding the emissions that would be associated with fuel combustion or greater electricity usage.

These technologies go a long way towards solving the heating and cooling challenges posed by residential and commercial buildings.

Methane is a potent GHG, with a warming potential more than 80 times higher than that of carbon dioxide over a 20-year period. Over the last 250 years, the concentration of methane in the atmosphere has increased by 167%, and in recent years methane concentrations have been increasing at a faster rate than at any point in history. Natural gas systems are one of the main contributors to methane emissions. In 2019, they were the second largest source of anthropogenic methane emissions in the US. Reducing fugitive methane emissions from the oil and gas industry is an enormous opportunity for reducing overall GHG emissions. Two technologies key to achieving this goal are advanced (1) methane leak monitoring and (2) leakless valves.

The transportation sector, which includes the movement of people and goods by cars, trucks, trains, ships, airplanes, and other vehicles, is the single greatest contributor to GHG emissions in the US. Although much of the focus on reducing emissions from the transportation sector is on fuel switching and fuel efficiency, there are other technologies with significant potential to reduce transportation-related GHG emissions. We highlight two: (1) light-weighting of cars, trucks, and airplanes using advanced materials and (2) additive manufacturing, or 3D printing. Light-weighting transportation vehicles reduces their fuel consumption and by extension their GHG emissions; however, the most promising advanced materials have not yet seen extensive commercial use. Additive manufacturing has the potential to build stronger structures with less material and thus less weight. In addition, additive manufacturing reduces scrap from conventional manufacturing, which eliminates the energy cost of reprocessing scrap metal. Finally, additive manufacturing can locate close to consumers, reducing the need for transportation across the country or across the globe, and eliminating the GHG emissions associated with such transportation.

We are not addressing the two major policy wedges for which the Administration already has programs in place (or will promptly put programs in place) – i.e., the decarbonization of the electric grid through renewables and large-scale energy storage and of the transportation sector through electric and hydrogen-fueled vehicles. The technologies profiled in this backgrounder address significant challenges that remain relatively under-addressed.

An important caveat: *Technologies described in this report are included for illustrative purposes only, and their inclusion should not be considered an endorsement. This document is intended to serve as a summary of what may be possible. We have sought to compile and contextualize the potential technologies, but we have not endeavored to test the claims made by the companies profiled in this backgrounder, and such technical evaluation is beyond the scope of our analysis. Earthshot™ and ASU welcome comment on the technologies and ideas presented in this paper.*

II. CEMENT MANUFACTURING

"Cement is a great example. It's over 6% of worldwide emissions. And yet, we don't have a way of doing it that's clean, that doesn't cost dramatically more, more than twice the price. So, if people think it's just passenger cars and electricity, they're going to miss what we need to do to get to zero." – Bill Gates (Feb 17, 2021)[2]

Cement production is the second-highest emitting industrial process in the US. If global cement production were its own country, it would be the third-highest emitting country, behind only China and the United States.[3] Carbon dioxide is a byproduct of the calcination process that is an essential step of traditional Portland cement manufacturing (and the process requires high temperatures, which necessitates combusting fossil fuels, further contributing to GHG emissions). Technologies to reduce the carbon footprint of cement manufacturing include capturing carbon dioxide from the cement manufacturing process and embedding it in concrete, using coal fly ash as a substitute for cement when mixing concrete, and replacing Portland cement with pozzolanic cement. Pozzolanic cement that reduces GHG emissions by 90% during the manufacturing process as compared to Portland cement is available and provides the opportunity to radically reduce the carbon footprint of cement manufacturing.

A. Overview of Cement Manufacturing

Concrete is the most widely used building material in the world.[4] Concrete is comprised of cement mixed with sand, gravel, and crushed rock. While the terms "concrete" and "cement" are often used interchangeably, it is *cement* production that produces significant GHG emissions. Cement is produced in 34 US states and Puerto Rico,[5] and cement manufacturing is one of the largest industrial sources of GHG emissions in the US.[6]

1. Portland Cement Production Releases Significant Amounts of CO_2

The majority of cement produced and in use today is Portland cement (named for the Isle of Portland in England, where it was invented approximately 200 years ago), and production of such cement results in two main categories of GHG emissions: process emissions and

[2] David Brancaccio and Daniel Shin, Bill Gates shares his plan for avoiding climate disaster, Marketplace, https://www.marketplace.org/2021/02/17/bill-gates-shares-his-plan-for-avoiding-climate-disaster/ (last visited May 4, 2021).

[3] Jonathan Watts, Concrete: the most destructive material on Earth, the Guardian (February 25, 2019), available at: https://www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth.

[4] *Id*.

[5] US EPA, Inventory of Greenhouse Gas Emissions and Sinks 1990–2019, EPA 430-R-21-005 (April 2021) at 4–10 (hereinafter "US EPA GHG Inventory").

[6] A. Pascale and C. Greig, Net-Zero America: Potential Pathways, Infrastructure, and Impacts, Annex K: Cement Industry Transition (Draft), Princeton University, Princeton, NJ, December 15, 2020 at 2 (hereinafter "Net-Zero America Report Annex K").

combustion emissions.[7] Of the total GHG emissions released in cement production, 60.6% (40.3 MMT CO_2e) come from process emissions, and 39.4% (26.2 MMT CO_2e) from combustion emissions.[8]

As to process emissions, cement production begins with making "clinker," the main component of cement. In this chemical process, a cement kiln is heated to extremely high temperatures (1,800 degrees Fahrenheit or higher) to break down limestone or similar rocks containing calcium carbonate ($CaCO_3$) into (1) calcium oxide (CaO) (also known as lime) and (2) carbon dioxide (CO_2).[9] This process of forming lime and CO_2 is called calcination or calcining.[10] The CO_2 created during calcination is vented to the atmosphere in the kiln exhaust (which forms the bulk of process emissions from cement production). The process continues by combining the CaO with other elements in the clinker raw materials, such as alumina, iron oxide and silica; cooling the clinker; and then finely grinding the clinker with small amounts of gypsum or other materials, like blast furnace slag or fly ash (also referred to as "supplementary cementitious materials" or SCM).

As to combustion emissions, as noted above, extremely high temperatures are required for the manufacturing process, which necessitates combusting fossil fuels.[11]

2. Quantifying GHG Emissions Impact of Cement Production

Concrete is one of the world's most popular building materials because it is durable, is relatively affordable, and can be used in a wide array of applications. Because of the large-scale use of concrete, its manufacture contributes 8% of global CO_2 emissions.[12]

In the US, over the period from 2015–2019, cement production process emissions (excluding combustion emissions) ranged from 39.0–40.9 MMT CO_2e per year.[13] Trends in CO_2 emissions from cement production roughly track overall economic trends. CO_2 emissions from

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[7] Additional upstream and downstream sources of emissions, accounted for in other categories of emission inventories, include mining and manufacture of lime, sourcing of supplementary cementitious materials, and transportation of raw materials and finished cement. Net-Zero America Report Annex K at 2.

[8] Net-Zero America Report Annex K at 3; based on 2017 emissions.

[9] US EPA GHG Inventory at 4–10.

[10] *Id.*

[11] MIT Concrete Sustainability Hub, Concrete Explainer, https://climate.mit.edu/explainers/concrete. One means of reducing the combustion emissions currently being studied is to replace the fossil fuel combustion with renewable hydrogen. *See* Mike Scott, "Here's How Hydrogen Could Clean Up The World's Dirtiest Industries," Forbes (April 6, 2020), https://www.forbes.com/sites/mikescott/2020/04/06/hydrogen-could-be-the-clean-fuel-of-the-future-for-the-dirtiest-industries/?sh=673e3a77988d; *see also* Scott Johnson, "Splitting water to make cement could clean up a dirty industry," Ars Technica (Sept. 17, 2019), https://arstechnica.com/science/2019/09/splitting-water-to-make-cement-could-clean-up-a-dirty-industry/.

[12] MIT Concrete Sustainability Hub, Embodied Concrete, available at: https://cshub.mit.edu/embodied-carbon; *see also*, Cement makers across world pledge large cut in emissions by 2030, The Guardian (October 12, 2021), available at: https://www.theguardian.com/business/2021/oct/12/cement-makers-across-world-pledge-large-cut-in-emissions-by-2030-co2-net-zero-2050.

[13] US EPA Draft Inventory at Table ES-2.

cement production rose from 1990 through 2006, and then fell until 2009 due to the economic recession and decrease in demand for building materials.[14] From 2010 through 2019, CO_2 emissions from cement production increased 30%, or 9.4 MMT CO_2e.

With a renewed emphasis on the nation's infrastructure, including highways, bridges, water systems, and housing,[15] the demand for concrete (and associated demand for cement production) could continue to grow, and perhaps more rapidly than we have seen in recent years. Along with rebuilding America's infrastructure, the Biden Administration recently announced a goal of reducing US GHG emissions by 50–52% below 2005 levels by 2030.[16] We can do both – with alternative and low-emission methods of producing cement, this Administration has the opportunity to build back America's infrastructure in a way that will reduce CO_2 emissions and help meet climate goals.

B. Technologies for Reducing Emissions from Cement Production

Several different technologies exist that reduce GHG emissions from cement production. The basic process descriptions, and how they differ from traditional cement production and reduce GHG emissions, are provided here.

1. Use of Coal Fly Ash as a Replacement for Traditional Portland Cement

Concrete is typically made from Portland cement, a controlled chemical combination of calcium, silicon, aluminum, iron and other ingredients described above. The cement is then mixed with water to form a paste that is poured into a cast and hardened.[17] As described above, manufacturing Portland cement is extremely carbon-intensive, with one ton of Portland cement requiring upwards of 1,000 pounds of CO_2 emissions to manufacture.[18]

Coal fly ash is often used in the concrete manufacturing process to reduce concrete's carbon footprint. Fly ash is a waste by-product of coal consumption, and it can be used to replace cement in concrete manufacturing. Usage of coal fly ash reduces emissions by the same percentage of cement the fly ash replaces. In addition to reducing carbon emissions, use of coal fly ash also improves the pumpability and flexibility of the concrete, reduces the amount of water needed to manufacture concrete, and produces concrete with greater strength and durability when

[14] *Id*. at 2–21.

[15] Fact Sheet: The American Jobs Plan (March 31, 2021), available at: https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/.

[16] Fact Sheet: President Biden's Leaders Summit on Climate (April 23, 2021), available at: https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/23/fact-sheet-president-bidens-leaders-summit-on-climate/.

[17] How Cement is Made, PCA, https://www.cement.org/cement-concrete/how-cement-is-made (last visited April 20, 2021).

[18] Marcello Rossi, Scientists Are Taking Concrete Steps Towards Reducing Cement's Massive Carbon Footprint (Nov. 15, 2019), https://qz.com/1748561/%E2%80%A8reducing-cements-carbon-footprint-is-critical-to-climate-fight/#:~:text=The%20process%20for%20making%20Portland,1%2C000%20pounds%20of%20carbon%20dioxide.

compared to concrete made with Portland cement.[19] Finally, concrete manufactured with fly ash is typically less expensive than concrete manufactured only with cement because fly ash is less expensive than cement. This technology has already been successfully used on a mass scale, so broad adoption of coal fly ash as a replacement for a portion of Portland cement in concrete could result in significant GHG emission reductions in the concrete industry. Although coal fly ash contains substances that can pose a human health risk, once coal fly ash has been encapsulated in concrete, US EPA has found that the encapsulated substances pose no unacceptable health risk.[20] The use of coal for power generation is decreasing, which limits the supply of coal fly ash. However, there are billions of tons of fly ash in landfills that could be harvested and reprocessed to replace Portland cement in concrete manufacturing.[21]

2. Embedding Carbon Dioxide in Concrete

Another technique to reduce carbon emissions from concrete manufacturing is to inject CO_2 into a wet cement mix. This process offsets CO_2 emissions from concrete manufacturing and also makes a stronger concrete.[22] Some companies using this technology are able to go even further to reduce carbon emissions. For example, the company CarbiCrete uses ground steel slag, a by-product of steel-making, instead of cement in its concrete manufacturing process. CarbiCrete then injects carbon dioxide into the concrete during the curing process to strengthen the steel slag mixture. This is a carbon-negative process, as CarbiCrete is able to avoid the GHG emissions associated with cement production and also inject carbon dioxide into its products.[23] Various concrete manufacturing plants have already successfully implemented this technology into their operations. For example, Thomas Concrete has installed technology for carbon dioxide injections in 26 of their plants, with 12 more plants slated for future installations.[24]

3. Growing "Cement" From Microorganisms

A third technology to reduce carbon emissions from concrete manufacturing is through the use of microorganisms. Biomason, a North Carolina company, created a process for microorganisms to grow "biocement" in ambient temperatures.[25] The process "combine[s] carbon and calcium to produce biologically formed limestone materials" which can then be used in place of cement to create concrete. The end result is carbon-neutral concrete that is three

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[19] Fly Ash Facts for Highway Engineers, Chapter 3 – Fly Ash in Portland Cement Concrete, Federal Highway Administration, https://www.fhwa.dot.gov/pavement/recycling/fach03.cfm#:~:text=Fly%20ash%20use%20in%20concrete,Benefits%20to%20Fresh%20Concrete (last visited April 20, 2021).

[20] US EPA, Coal Combustion Residual Beneficial Use Evaluation: Fly Ash Concrete and FGD Gypsum Wallboard (February 2014), available at: https://www.epa.gov/sites/default/files/2014-12/documents/ccr_bu_eval.pdf.

[21] *See* Austin Gaffney, Can Harvest Rare Earth Elements Solve the Coal Ash Crisis?, Sierra Club (February 17, 2021), available at: https://coal.sierraclub.org/posts/can-harvesting-rare-earth-elements-solve-coal-ash-crisis.

[22] CarbonCure, https://www.carboncure.com/technology/ (last visited April 20, 2021).

[23] Technology, CarbiCrete, https://carbicrete.com/technology/ (last visited April 21, 2021).

[24] Pillars of Strength: Thomas Concrete, CarbonCure, https://www.carboncure.com/resources/thomas-concrete/ (last visited April 21, 2021).

[25] Technology, Biomason, https://biomason.com/technology/ (last visited April 21, 2021).

times stronger than traditional concrete and 100% recyclable.[26] This technology is especially suited for use in marine environments. Biomason claims that its "biocement" contains a "proprietary consortia of self-sustaining natural marine microorganisms" that are capable of using nutrients in seawater; this results in concrete that has improved structural integrity, better anchoring to the marine sediment floor (when used in marine environments).[27] Biomason currently sells pre-cast building materials created using its technology, but does not offer the "biocement" itself to other concrete manufacturers.[28]

4. Pozzolanic Cement

When Portland cement was invented approximately 200 years ago, it replaced pozzolanic cement, which was invented more than 2,000 years ago (in Pozzouli, Italy, near Naples) and used to build ancient Rome and Athens.

Portland cement has one advantage over pozzolanic cement – it hardens about five times faster, enabling construction to start within days after pouring the concrete. By all other measures, however, pozzolanic cement is superior. It continues to harden over time reaching strengths that are 20 to 100% stronger than Portland cement. Its durability is about four times better than that of Portland cement, which is why ancient Rome and Athens are still standing today while Portland cement constructed 50 years ago often evidences significant decay. The manufacturing costs of Portland cement and pozzolanic cement are roughly the same.

Critically, pozzolanic cement does not have the same GHG emissions problem that Portland cement does: pozzolanic cement is formed at room temperature (so there is no need to combust fossil fuels to heat a kiln to extreme temperatures, as is the case with Portland cement), and pozzolanic cement does not emit carbon dioxide as a byproduct.

C. Example Company: Green Cement Inc. – Pozzolanic Cement

Green Cement Inc. manufactures "PozzoSlag," a pozzolanic cement that significantly reduces GHG emissions during manufacturing and uses waste from coal-fired power plants[29] as well as natural mineral pozzolans. Pozzolans are compounds that are high in silica (or aluminum) and react with calcium hydroxide. When mixed with Portland cement (CaO) and water, the pozzolans react to form calcium silicate hydrate, a compound with cementitious properties.

PozzoSlag is a replacement for Portland cement and generates 95% lower carbon emissions in the production process, according to Green Cement.[30] The patented process uses as

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[26] *Id*.

[27] *Id*.

[28] Biolithe, Biomason, https://biomason.com/biolith/ (last visited April 21, 2021).

[29] Green Cement, www.greencement.com.

[30] Business Wire, VHSC Cement Improves Its Game-Changing, Cost Saving Pozzoslag Concrete Product (July 15, 2013), https://www.businesswire.com/news/home/20130715005331/en/VHSC-Cement-Improves-Its-Game-Changing-Cost-Saving-Pozzoslag%C2%AE-Concrete-Product.

its feedstock natural pozzolans (such as volcanic ash) or coal fly ash (a pozzolanic material). In the case of the latter, the process reuses a waste product that would otherwise be placed in landfills or ash ponds.

PozzoSlag significantly reduces emissions because it does not rely on a kiln for production, thereby eliminating the high-energy demand of Portland cement. Additionally, in contrast to Portland cement, the production process for PozzoSlag does not involve a reaction that releases CO_2, as in the production of clinker. As described above, about 60% of the GHG emissions from traditional Portland cement manufacturing result from the chemical release of CO_2, while process emissions comprise the balance. GHG emissions from energy to heat the kiln comprise the bulk of the process emissions for Portland cement manufacturing, but about 5% of the total emissions result from the electricity to run the mills and other process equipment. Pozzoslag requires similar electricity consumption to mill Pozzoslag into a fine powder. But Pozzoslag requires no energy to heat a kiln, and there is no chemical release of CO_2. As such, the manufacture of Pozzoslag generates 5% as much greenhouse gas as Portland cement – or a 95% reduction in total carbon output.

The process for manufacturing Pozzoslag consists of milling a pozzolan (e.g., fly ash or volcanic ash) and adding chemicals. The milling technique increases the surface area of the pozzolan, exposing more area for chemical reactions. The chemical additives make these exposed areas more reactive. Additionally, the milling and added chemicals minimize water demand of the cement. Strength of concrete is inversely proportional to water demand; thus, minimizing water demand is important. An additional benefit of the process is that pozzolanic cement creates a better barrier to reactions that damage concrete (including alkali-silicon reactions and reactions caused by chlorine or sulfur permeating concrete). Preventing these adverse reactions makes pozzolanic cement much more durable than Portland cement.

Green Cement's operating costs are comparable to manufacturing Portland cement. However, because Pozzoslag does not require a high temperature kiln, the capital costs of a Green Cement plant are about 80% lower than for traditional Portland cement plants. The lower capital costs allow for economical operation of Green Cement plants at lower throughputs than traditional Portland cement plans, which by extension allows plants to be located closer to markets – reducing transportation costs and associated GHG emissions. Finally, Green Cement utilizes waste materials, making it a preferred and more environmentally friendly alternative.

In addition to these environmental and economic benefits, PozzoSlag is stronger and more durable than traditional Portland cement. Green Cement's process increases the reactivity of fly ash such that a 50/50 mixture with Portland cement creates concrete that achieves the strength of 100% Portland cement within one day. The 50/50 mixture increases strength over time such that after 28 days the PozzoSlag mixture is 20% stronger than 100% Portland cement.[31] Stronger and more durable cement will further reduce cement-production emissions, as it will last longer and reduce the quantity of cement required by 60%.[32]

[31] Green Cement, Products & Services, https://www.pozzoslag.com/products-services.

[32] Green Cement, https://pozzoslag.com/company/30-vhsc-s-product-has-been-deployed-by-customers-throughout-the-texas-market.

Pozzoslag has been approved by the Federal Highway Administration, the Texas Department of Transportation, and other agencies for use on highways as a 50/50 mixture with Portland Cement. Additionally, a version of Pozzoslag called PozzoCem is available as a 100% replacement for Portland Cement, and many customers use Green Cement products to replace more than 50% of Portland cement, according to the company.

The availability of newly produced coal fly ash is declining rapidly in the US as coal-fired power plants are replaced by renewable energy. There are two alternatives for newly produced fly ash: landfilled fly ash and natural pozzolans (the latter being mostly volcanic ash). Both alternative sources are plentiful and are demonstrated at commercial scale to make a quality pozzolanic cement.

Green Cement Inc., is based in The Woodlands, Texas, and operates a production facility in Jewett, Texas. PozzoSlag has been commercially deployed in Texas, where it has been used in highways, roads, building foundations, airports, down hole cement, and precast concrete products.[33] The Green Cement products are certified for use by the City of Austin, Texas; City of Dallas, Texas; the Federal Highway Administration; and the Texas Department of Transportation.[34]


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<u>Pozzoslag used in pre-cast pipe and used for I45 between Houston and Dallas</u>

[33] Green Cement, About Us, https://www.pozzoslag.com/about-us.

[34] Green Cement, Products & Services, https://www.pozzoslag.com/products-services.

[35] Source: Green Cement.

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Pozzolanic cement after 2,000 years (built in 125 AD, the Pantheon is the world's largest unreinforced concrete dome)

D. Example Company: CarbonCure – Concrete Embedded with Carbon Dioxide

CarbonCure Technologies Inc. ("CarbonCure") manufactures concrete that contains recycled CO_2, which reduces the concrete's carbon footprint without compromising on performance.[37] CarbonCure produces their concrete by injecting CO_2 directly into concrete mix. Once injected, the CO_2 reacts with calcium ions to mineralize and become calcium carbonate. The mineralized CO_2 then becomes permanently embedded in the concrete.[38] The embedded CO_2 increases the concrete's compressive strength, which reduces the amount of cement needed in the finished product.[39]

CarbonCure sources its CO_2 from industrial emitters. The gas is collected, purified, and stored in pressurized tanks. The CO_2 is then injected into an existing hopper or central mixer at existing concrete plants (although the equipment must be retrofitted with a device from CarbonCure). CarbonCure currently offers this technology for ready mix concrete, precast concrete, and concrete masonry.

By taking CO_2 that otherwise would have been emitted into the atmosphere, CarbonCure is able to reduce the carbon footprint of its concrete by approximately 25 pounds of CO_2 per

[36] Source: Green Cement

[37] CarbonCure, https://www.carboncure.com.

[38] Innovative CO2 Technology, CarbonCure, https://www.carboncure.com/technology/.

[39] CarbonCure, CarbonCure's 500 Megatonne CO2 Reduction Technical Roadmap, available at: http://go.carboncure.com/rs/328-NGP-286/images/CarbonCure%27s%20500%20Mt%20CO2%20Reduction%20Technical%20Roadmap%20eBook.pdf.

cubic yard, which is a 6% reduction from typical emission levels from concrete production.[40] While concrete naturally sequesters atmospheric CO_2,[41] CarbonCure's concrete solution produces a more durable end product. The company's studies indicate that mineralized CO_2 increases concrete's compressive strength by up to 10% at 28 days following production. As a result, CarbonCure discovered that it could reduce cement content by 7%, supplement the reduced cement content with injected CO_2, and produce a resulting mix with strength equal to that of standard concrete.[42] This means that CarbonCure technology can also enable concrete plants to reduce their use of cement, which carries the bulk of concrete's carbon footprint. Reducing the amount of cement needed to produce durable concrete is the dominant factor in achieving CarbonCure's claimed CO_2 emissions levels.[43]

CarbonCure is based in Canada and was founded in 2007 by Rob Niven. Its technology has been commercially deployed by more than 300 concrete producers currently in Canada and the United States.[44] CarbonCure has also attracted the attention of large corporations; one example is Amazon, which, in building its Virginia headquarters, has committed to using more than 100,000 cubic yards of CarbonCure concrete that will sequester approximately 2.5 million pounds of CO_2.[45] The company recently won the Carbon XPRIZE, a global competition which awarded its winners a $7.5 million grand prize to combat climate change.[46]

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[40] One cubic yard of concrete typically releases 400 pounds of CO2. Concrete and CO2, National Precast Concrete Association (May 22, 2013), https://precast.org/2013/05/concrete-and-co2/.

[41] Zhi Cao et al., The Sponge Effect and Carbon Emission Mitigation Potentials of the Global Cement Cycle, Nature Communications (July 29, 2020), https://www.nature.com/articles/s41467-020-17583-w. Cao et al. conclude that the natural "sponge effect" of concrete sequesters the same or slightly higher volume of atmospheric CO2 as the process of carbon storage and capture.

[42] Ready Mix Technology Trial Results, CarbonCure, http://go.carboncure.com/rs/328-NGP-286/images/CarbonCure%20Technical%20Note%20-%20Ready%20Mix%20Technology%20Trial%20Results.pdf.

[43] CarbonCure, CarbonCure's 500 Megatonne CO2 Reduction Technical Roadmap, available at: http://go.carboncure.com/rs/328-NGP-286/images/CarbonCure%27s%20500%20Mt%20CO2%20Reduction%20Technical%20Roadmap%20eBook.pdf

[44] Producers, CarbonCure, https://www.carboncure.com/producers/.

[45] Amazon HQ2, CarbonCure, https://go.carboncure.com/rs/328-NGP-286/images/CC_OP-MillerandLong-AmazonHQ2.pdf.

[46] Clean Tech Company, CarbonCure Wins NRG COSIA Carbon XPRIZE, CarbonCure, https://www.carboncure.com/news/clean-tech-company-carboncure-wins-nrg-cosia-carbon-xprize/.

III. HEATING AND COOLING OF RESIDENTIAL AND COMMERCIAL BUILDINGS

The United Nations Intergovernmental Panel on Climate Change ("IPCC") has repeatedly identified buildings as a critical field for climate action.[47] Contributing 38% of energy-related global GHG emissions, the buildings sector consists of residential, commercial, and public properties.[48] Heating and cooling systems in particular consume large quantities of energy, and there are many different technologies that can be deployed to reduce building energy consumption:[49]

- Structural insulated panels are pre-fabricated interior and exterior construction panels with protective thermal ratings to reduce the need for heating and cooling and make it less expensive and more efficient to build new buildings.

- Energy efficient windows reduce the loss of energy through windows via heat transfer, and embedding photovoltaics into the windows provides an additional energy source.

- Tempered vacuum-insulated glass windows are specially treated advanced windows that also provide low levels of thermal losses.

- Sealing HVAC systems to eliminate small leaks in heating and cooling ductwork has been demonstrated to reduce HVAC leakage rates significantly, reducing GHG emissions.

- Sorbent air cleaning technology for commercial buildings can materially reduce the need to pull large volumes of outside air into buildings to maintain good indoor air quality, which in turn materially reduces the need for energy to heat or cool outside air.

- Also with respect to commercial buildings, smart HVAC systems use sensors and controllers to capture a vast amount of data, and then analyze, predict, and control

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[47] Intergovernmental Panel on Climate Change (IPCC). Summary for Policymakers. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty; 2018. ISBN 978-92-9169-151-7. *See also* H. de Coninck, A. Revi, M. Babiker, P. Bertoldi, M. Buckeridge, A. Cartwright, et al. Strengthening and Implementing the Global Response Global Warming of 1.5°C, IPCC Special Report (2018).

[48] US Energy Information Administration, Monthly energy review – September 2019, (DOE/EIA-0035[2019/9], US Energy Information Administration, Washington, DC, 2019); US Department of Energy – Energy Information Administration. Annual Energy Outlook 2020. Table A2 Energy Consumption by Sector and Source. https://www.eia.gov/outlooks/aeo/.

[49] Besides ambient heating and cooling, the 28% figure includes cooking, water heating, and, in commercial buildings, process heating.

building energy usage – ensuring that HVAC systems run only when, where, and as much as is needed, to eliminate hot spots and minimize energy usage.

- Finally, in the residential space, geothermal energy systems harness subsurface energy to provide heating and cooling, allowing homeowners to stop the use of natural gas, propane, or fuel oil combustion for home heating, and to reduce or eliminate air conditioner usage, avoiding the emissions that would be associated with fuel combustion or air conditioner electricity usage.

These technologies go a long way towards solving the heating and cooling challenges posed by residential and commercial buildings.

A. Overview of Heating and Cooling of Residential and Commercial Buildings

Energy used for heating and cooling commercial and residential buildings is one of the greatest contributors to an individual's carbon footprint.[50] Roughly 20% of US energy-related GHG emissions stem from heating, cooling, and powering households,[51] and another 18% of US primary energy use stems from commercial buildings.[52] If considered a country, these US commercial and residential building sector emissions would function as the world's sixth greatest GHG emitter, comparable to Brazil and larger than Germany.[53] Despite the increasing energy efficiency of buildings over time, the climate impact of heating and cooling buildings has increased, with 2019 being the worst year on record for GHG emissions from the building sector.

Heating has been the most significant contributor to building GHGs, accounting for 38% of delivered energy from buildings in 2019 – larger than any other end use. This trend, however, has begun to shift: in the Annual Energy Outlook 2020, the US Energy Information Administration ("EIA") projected that delivered energy for air-conditioning will increase more than any other end use in residential and commercial buildings through 2050, while energy consumption for space heating will decline. There are several reasons for the increase in air-conditioning, including increasing incomes, population growth in warmer regions, and the general trend of all new homes being built with air-conditioning regardless of their geographic location. As summer temperatures rise in parts of the country that did not traditionally have air-conditioning, this trend will likely accelerate. Increasing heat waves, such as the 2021 heat waves in cities like Portland, might push more people to install air-conditioning. By contrast, the

[50] How to cut carbon out of your heating, BBC news, available at: www.bbc.com/future/article20201116-climate-change-how-to-cut-the-carbon-emissions-from-heating.

[51] US Energy Information Administration, Monthly energy review – September 2019, (DOE/EIA-0035[2019/9], US Energy Information Administration, Washington, DC, 2019).

[52] US Department of Energy – Energy Information Administration. Annual Energy Outlook 2020. Table A2 Energy Consumption by Sector and Source. https://www.eia.gov/outlooks/aeo/.

[53] World Resources Institute, Historical emissions. CAIT Climate Data Explorer (2014). http://cait.wri.org. Accessed October 2, 2019.

EIA projects that from 2019 to 2050, delivered energy consumed for space heating will fall by more than 1.5 quadrillion British thermal units – the largest decline among end uses.

Growth in residential and commercial cooling is especially concerning as, in addition to fossil fuel combustion emitting carbon dioxide, cooling emits hydrofluorocarbons ("HFCs") and other refrigerants, which are 4,000 times more potent than carbon dioxide.[54] In any case, the US has long consumed more energy each year for air-conditioning than the rest of the world combined, contributing to 117 million metric tons of carbon dioxide and using 6% of the nation's electricity.[55] The majority of this comes from office building use, which accounts for 25% of the energy consumed for air-conditioning in the US commercial sector.

To address the significant GHG emissions associated with residential and commercial building operation, the Biden Administration has made energy efficiency measures a top policy priority.[56]

B. Technologies for Reducing Emissions Associated with the Heating and Cooling of Buildings

Reducing the demand for heating and cooling by making buildings more energy efficient has the potential to materially decrease GHG emissions from buildings. We summarize below several technologies with significant potential to achieve emissions reductions in the buildings sector: (i) replacing traditional construction methods for floors, walls, and roofs with energy efficient building panels, (ii) photovoltaic windows, which generate energy, and advanced windows that are highly energy efficient, (iii) HVAC system operational efficiency improvements, and (iv) geothermal energy systems.

1. Energy Efficient Building Panels

Structural insulated panels ("SIPs") are high-performance engineered building panels used to construct walls, floors, ceilings, roofs for residential and commercial buildings.[57] SIPs are typically made using expanded polystyrene or polyisocyanurate rigid foam insulation sandwiched between two structural skins of oriented strand board. SIPs offer superior thermal resistance and insulation and offer a more airtight system as compared with traditional construction materials. This allows the building envelope to regulate heating, cooling and, humidity, resulting in less energy usage. SIP homes are approximately 50% more energy

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[54] How America became addicted to air conditioning, The Guardian: https://www.theguardian.com/environment/2015/oct/26/how-america-became-addicted-to-air-conditioning.

[55] Air Conditioning, available at: https://www.energy.gov/energysaver/home-cooling-systems/air-conditioning#:~:text=Air%20conditioners%20use%20about%206,into%20the%20air%20each%20year.

[56] FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing US Leadership on Clean Energy Technologies (Apr. 22, 2021), available at: https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/.

[57] Structural Insulated Panels: A Sustainable Option for House Construction in New Zealand?, Int. Journal for Housing Science, Vol.32, No.1 pp. 15–27, 2008, available at: https://www.housingscience.org/html/publications/pdf/32-1-2.pdf.

efficient than traditional timber framing, according to the Structural Insulated Panel Association.[58] Made from renewable sources and manufactured in a factory, resulting in less waste material, SIPs provide environmental benefits that extend beyond a reduction in heating and cooling. SIPs are, however, more expensive than employing traditional construction methods, costing approximately 15% more than standard stud frames and may, therefore, be better suited to new constructions.

2. Photovoltaic and Energy Efficient Windows

Traditionally, windows have been the weakest energy efficiency link in a building envelope, with early single-pane windows being the most egregious offenders. Indeed, according to the Department of Energy ("DOE") of the United States, between 25% and 35% of energy in buildings is wasted due to inefficient windows. The energy efficiency of a window is normally identified by its R-values, which quantifies the window's resistance to heat flow. The California Energy Commission estimates that about 40% of the cooling demand of a typical building is due to the solar heat gain through windows.

There have been advances in sustainable windows, from multi-layer glazing to low emissivity glass. Using a thin coating of a highly reflective material, low-e glass enables light to pass through the glass but controls the direction of heat transfer to either cool or heat a room depending on the way in which the coating has been applied. Low emissivity glass has been highly effective in reducing energy demand, reducing heat loss by more than 70% and saving a typical US home up to $500 a year.[59]

The majority of advanced window designs to date have a static R-value, optimized for cooler or hotter climates (and do not function optimally in environments where there is a need to alternate between heating and cooling). Another method of window improvement involves moderating R-values by changing the translucence of windows in response to external environmental conditions and user needs, limiting the transmission of the radiant energy of light. For instance, electrochromic windows change transparency based on temperature and light level and require limited power to initiate, such that 100 windows (1,500 square feet) would need less than a 75 watt light bulb.[60]

Also, and as highlighted below, improvements to window design via tempering and vacuum sealing the space between panes have achieved high R-values, which can then capture the benefits of other technologies through pairing of the window with passive cooling construction or blinds.

Finally, and also as highlighted below, solar windows are now available. These windows counterbalance the loss of energy through windows via heat transfer by generating their own energy.

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[58] Structural Insulated Panel Association, What are SIPS?, available at: https://www.sips.org/what-are-sips.

[59] Smart Windows: Enhancing the energy efficiency of buildings at: https://www.coins-global.com/storage/documents/Emerging-Technologies-for-the-Built-Environment-Smart-windows.pdf.

[60] *Ibid.*

3. HVAC System Operational Efficiency Improvements

A number of technologies have emerged in recent years to address the massive amounts of energy that HVAC systems consume through making such systems operate more efficiently. Operational efficiency improvements can be achieved in a variety of ways.

First, sealing HVAC systems to eliminate small leaks in heating and cooling ductwork has been demonstrated to reduce HVAC leakage rates significantly, making HVAC systems more efficient, which reduces associated energy usage – as well as GHG emissions.

Second, with respect to commercial buildings, a primary goal of traditional ventilation systems is to maintain indoor air quality by introducing significant quantities of outside air into the indoor environment. HVAC systems are traditionally designed to regulate intake of outdoor air to satisfy guidelines for airflow rate. This outside air must then be heated or cooled, which requires significant energy usage. Sorbent-based air cleaning technology can materially reduce the need for outside air to maintain good indoor air quality by cleaning indoor air at the source, which in turn materially reduces the need for energy to heat or cool outside air.

Third, and also with respect to commercial buildings, "smart" HVAC systems offer the opportunity to address the energy wasted by traditional HVAC systems heating and cooling when and where there is no need. Smart HVAC systems use sensors and controllers to capture a vast amount of data and then analyze, predict, and control building energy usage. Such systems are intended to ensure that HVAC systems run only when, where, and as much as is needed, to eliminate hot spots and minimize energy usage.

4. Geothermal Energy Systems

Whereas the above HVAC technologies focus on efficiency gains, residential geothermal energy systems harness subsurface energy to provide heating and cooling, allowing homeowners to stop the use of natural gas, propane, or fuel oil combustion for home heating, and to reduce or eliminate air conditioner usage, avoiding the emissions that would be associated with fuel combustion or air conditioner electricity usage.

C. Example Company: Vantem Global – Structural Insulated Panels (SIPs) for Use in Pre-Fabricated Construction

Vantem Global offers a proprietary SIP called Vantem Cement Board, which is a light structural panel with proprietary cement faces sandwiching an insulated core.[61] The panels are strong, light, and rated for homes and commercial use.

Cement Boards also provide various environmental benefits throughout the life of the building. Vantem's system has been rated as five times more thermally efficient than brick and mortar construction.[62] Vantem's SIPs are moisture, mold, termite, and fire resistant and rated for

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[61] https://vantemglobal.com/.

[62] Vantem is certified to meet the requirements of 2021 International Building Code and 2021 International Residential Code in many countries. US certification is expected in Q1 2022, according to the Company.

use in various climate conditions – wet tropical areas, deserts, and cold regions. These features prolong the life of the building, reducing the impact of rapid construction cycles.

SIPs have practical benefits beyond environmental benefits. Vantem's SIPs are rated to support up to 18,000 kg of load and are approved for both exterior and interior walls as well as ceilings.[63] Unlike some other alternative construction materials, Vantem Cement Boards are cement-based, making them compatible with existing building codes, which allows for their use in multiple jurisdictions. Panels are also rated for use in seismic areas. The Boards themselves are planned to be manufactured in factories which can be placed near the final use point, allowing for year-round construction at a fast rate, as 100,000 square feet of panels per month can be produced in one plant shift. Unlike brick and cement, the light panels can be shipped and handled with ease. In particular, panels can be handled manually – eliminating the need for heavy equipment during building construction, and pre-fabrication allows for assembly with only the use of handheld power tools.[64]

While certain materials are limited to use in certain construction types, Vantem's Cement Boards are rated for single-family homes, high-rises, public buildings, and mobile homes. Vantem's panels decrease material demand, reducing both cost and environmental impact by eliminating the need for cement, steel, and other reinforcements.[65] Full-scale production was launched in 2019 in South America and the Caribbean, where more than 1,000 homes, 100 schools, a university campus, and many other buildings have been built with Vantem's SIPs. Vantem's pre-fabricated construction was recently demonstrated at a luxury hotel in Uruguay.[66]

Vantem Global is headquartered in Arlington, Massachusetts. Vantem Global has previously relied on manufacturing in China and Uruguay, and reportedly plans to open a manufacturing plant in the US in 2022.

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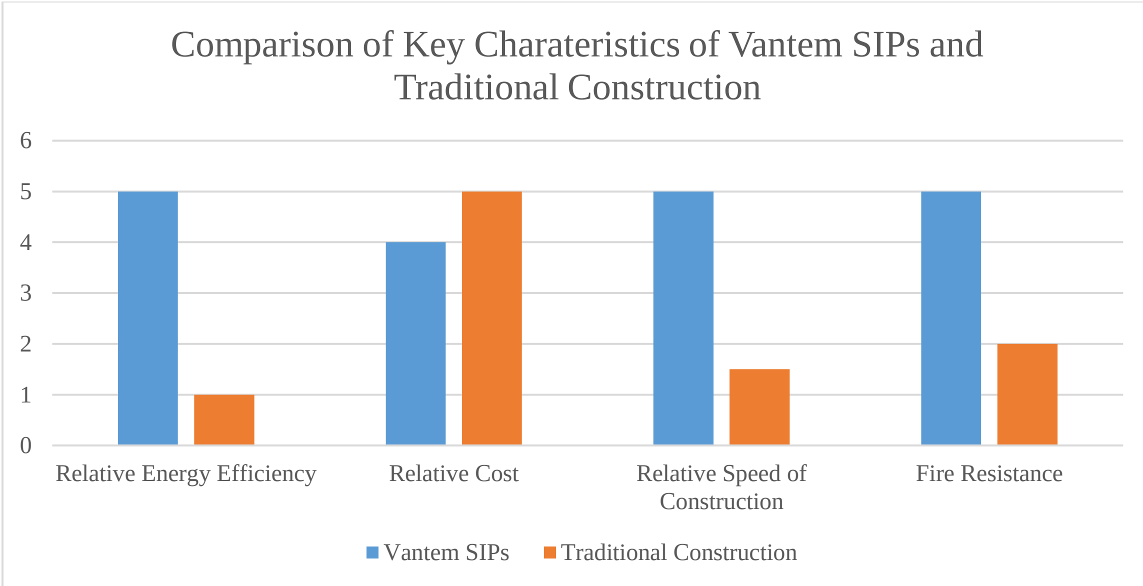
[63] Vantem Global, Paneles Estructurales Termoaislantes Intelitec, Structural Insulated Panels, available at: https://vantemglobal.com/wp-content/uploads/2014/04/VA_C04-FichaTecnicaPanel-A4-201611.pdf.

[64] Vantem Global, Vantem's Products, available at: https://vantemglobal.com/#products.

[65] Vantem Global, Vantem's Products, available at: https://vantemglobal.com/#products.

[66] Vantem Global, Vantem Global Introductory Video, available at: https://www.youtube.com/watch?v=u9MnHVn0uYw.



[67]

<u>Office Building Constructed with Vantem SIPs</u>

Vantem's technology lends itself to modular pre-fabrication, which can lower costs and improve quality. Pre-fabrication also eliminates weather-related problems at the construction site. The building of a luxury hotel in four months recently demonstrated the benefits of pre-fabrication. The rooms for the hotel were built in the factory.

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[67] Source: Vantem


[68]

Pre-fab hotel rooms built in Vantem's factory and finished rooms installed on site.


[69]

Rendering of the finished hotel.

Vantem's pre-fabricated construction with SIPs enables cost to be lower than conventional construction with better quality, the simplicity enables construction to be significantly faster, and the buildings require about 70% less energy to heat and air-condition, according to Vantem.[70]

D. Example Company: Next Energy Technologies – Solar Windows

Next Energy Technologies ("Next") produces solar windows: transparent, energy-producing windows which serve as a source of cost-effective on-site renewable power.[71] Next's transparent photovoltaic coatings turn windows, a historical weak link in the energy efficiency chain, into a tool for buildings to power themselves. Next began at the University of

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[68] Source: Vantem

[69] Source: Vantem

[70] Vantem, available at: https://netcapital.com/companies/vantem-global-llc.

[71] Next Energy Technologies, available at: https://www.nextenergytech.com/.

California Santa Barbara's Institute for Energy Efficiency ("UCSB IEE"), and its technology uses breakthrough organic semiconductors pioneered at the university.[72]

The Next technology is essentially a semiconducting ink that is printed directly on glass during the window fabrication process. Next uses a small molecule organic photovoltaic technology (referred to as "SSM-OPV") which enables solar cells to be printed as an ink in a low-cost, roll-to-roll process akin to printing a newspaper or photographic film. The printing process uses slot die coating equipment, which was first used for the production of photographic films in the 1950s and has recently been used in the printed electronics and display industries. Next's ink is produced using organic semiconducting materials that are earth-abundant and low cost.

In operation, Next's semiconducting ink converts unwanted infrared and ultraviolet light into electricity. Individual windows distribute energy to the building where they are located using PV inverters, power optimizers, and wiring.

At the same time, the windows allow visible light to pass through, not degrading transparency in the least. Next's windows match low-e coatings in terms of color, haze, clarity, visible light transmission, and solar heat gain performance. While the main purpose of the company's windows is to generate energy, the unique ability of Next's windows to convert light into electricity (rather than heat) decreases the solar heat gain coefficient, improving building energy efficiency.[73]

Next's solar windows are cost-competitive with other conventional solar-generating technologies. In part, this is because Next's windows can be directly integrated into traditional commercial window and framing systems, which avoids the costs associated with procuring, installing, and maintaining standalone solar arrays. Also, in contrast to standard solar cells, which are commonly made from elements such as carbon, hydrogen, nitrogen, fluorine, oxygen, and sulfur, Next's carbon-based materials are inexpensive and abundant, leading to organic photovoltaic materials that are less expensive to produce. Next's solar cells are also lighter and more flexible, and are recyclable as easily as standard commercial window glass.

UCSB has found that Next's SSM-OPV materials dramatically improve the scalability, stability, and efficiency over previous generations of organic photovoltaic technology, resulting in product lifetimes and conversion efficiencies that can be competitive with conventional solar technology.[74]

Next is based in Santa Barbara, California. Next has been supported by the National Science Foundation, California Energy Commission ("CEC"), the, DOE (including with a $2.5 million grant from the DOE SunShot Initiative)[75] and the UCSB Center for Energy Efficient

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[72] University of California Santa Barbara Institute for Energy Efficiency, Next Energy Technologies – Organic Solar Start-Up (October 2013) ("USCB Overview"), available at: https://iee.ucsb.edu/next-energy-technologies-organic-solar-start.

[73] https://in2ecosystem.com/companies/next-energy-technologies-inc/.

[74] UCSB Overview.

[75] *See* https://www.glassonweb.com/news/next-energy-technologies-wins-usd-25m-doe-award-solar-window-tech.

Materials. In April 2021, Next raised $13.4 million in Series C funding and was awarded a $3M grant from the CEC.[76]

E. Example Company: VIG Technologies – Tempered Vacuum Insulating Glass Windows

VIG Technologies offers LandVac Tempered Vacuum Insulating Glass (LandVac), a high-performing window option that increases thermal performance and reduces noise pollution and condensation.[77] Responding to the growing trend in local building codes to refocus building energy concerns onto carbon emissions, LandVac glass offers a thermal insulation solution that responds to many of the concerns identified above about windows as a weak point in building heating and cooling.

LandVac glass is 100% fully tempered vacuum-insulated glass which is rated for use across temperature extremes. LandVac glass is more energy efficient than alternative glass options. The glass is two to four times more efficient than insulated glass, six to ten times more efficient than single pane glass, and meets all international passive house heat transfer requirements on windows and doors.[78] For instance, as detailed in the table below, conventional glass options have an R-value of roughly 1 to 6; by contrast, LandVac vacuum-insulated glass is an order of magnitude better with an R-Value of 14.30. This R-value can then be further improved through combining LandVac windows with blinds, to reduce heating from light radiation.

The glass has several beneficial environmental attributes. Each glass unit is rated for use for 40 years or more, reducing consumer costs and the energy intensity of building construction obligations. LandVac glass is thin and lightweight, allowing for seamless integration into existing frames, making it an accessible option for a larger set of consumers. In addition, the glass itself is Safety Glazing Certification Council-certified, making it a safer option for both the home and the workplace. Finally, the product itself is made of lead-free recycled materials, providing a competitive advantage against the supply chain of competitors.[79]

The following table compares single pane glass, insulated glass, triple glass, and LandVac glass, demonstrating the product's ability to combine performance with aesthetic appeal.

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[76] https://www.finsmes.com/2021/06/next-energy-technologies-raises-13-4m-in-series-c-funding.html.

[77] https://www.vigtechnologies.com/

[78] VIG Technologies, Our tVIG, available at: https://www.vigtechnologies.com/our-tvig.

[79] VIG Technologies, VIG Glass Brochure, available at: https://5ea92936-b8ba-4094-b31e-a607f7f96f4b.filesusr.com/ugd/f2bcc2_9a69f3fa8ae34530989beeba95e8db7f.pdf.

Parameters	Single Glass	Insulated Glass	Triple Glass	LandVac
U -Value(W/m2 K)	5.68	1.53	1.02	0.40
Btu/h·ft2·F	1.00	0.27	0.18	0.07
R-Value	1.00	3.70	5.56	14.30
Thickness	6-10mm	25.4mm	44.4mm	8.3mm
Visible Light Transmittance	90%	70%	63%	70%
The Weighted Sound Reduction Rw (C;Ctr)	29 (-2;-3)dB	31 (-2;-5)d	32 (-1 ;-5)dB	36 (-2;-3)dB
Seal Strength	NA	150psi	150psi	3000psi

[80]

VIG Technologies LandVac tVIG Parameter Comparison[81]

VIG Technologies is headquartered in Jupiter, Florida.[82]

F. Example Company: Aeroseal – HVAC Leak Sealing

Aeroseal developed a technology for sealing leaks in air ducts in both residential and commercial buildings.[83] Sealing HVAC systems to eliminate small leaks in heating and cooling ductwork has been demonstrated to reduce HVAC leakage rates by approximately 95% in many buildings. This reduction in HVAC leakage rates makes HVAC systems 20–30% more efficient, which reduces associated energy usage – as well as GHG emissions – by the same amount.

A Lawrence Berkeley National Laboratory ("LBNL") energy performance expert formulated the idea for Aeroseal in the 1990s.[84] The LBNL team identified a way to seal leaks from inside ducts (as opposed to traditional leak sealing methods, which attempt to seal leaks from duct exteriors), and to do so using computer automation instead of traditional manual

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[80] Source: VIG Technologies

[81] VIG Technologies, VIG Glass Brochure, available at: https://5ea92936-b8ba-4094-b31e-a607f7f96f4b.filesusr.com/ugd/f2bcc2_9a69f3fa8ae34530989beeba95e8db7f.pdf.

[82] Dun & Bradstreet Business Directory, VIG Technologies LLC, available at: https://www.dnb.com/business-directory/company-profiles.vig_technologies_llc.5a9761e1555df7afc6c50de191120f24.html#financials-anchor.

[83] www.aeroseal.com

[84] Department of Energy Office of Energy Efficiency and Renewable Energy, *EERE Success Story – Aeroseal and Lawrence Berkeley National Laboratory Develop Technology to Find and Fill Building Energy Leaks* (December 13, 2016), available at: https://www.energy.gov/eere/success-stories/articles/eere-success-story-aeroseal-and-lawrence-berkeley-national-laboratory.

methods.[85] Aeroseal's technology works by pressurizing HVAC systems and then injecting a fog of sealant particles (of 3 to 15 microns) into the systems, effectively sealing system leaks as small as the width of a human hair.[86] The sealant injection process is controlled by software Aeroseal developed to improve efficacy and uses specialized nozzles, which control the atomization of the sealant. The sealant is a GreenGuard Gold certified water-based sealant.[87]

Photo Courtesy | Lawrence Berkeley National Laboratory [88]

Aeroseal's technology has now been applied in more than 200,000 buildings, and leak flow testing prior to and following application demonstrates that ductwork leakage is regularly

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[85] *Id*.

[86] *See* https://aeroseal.com/aerobarrier/how-aerobarrier-works/.

[87] *See* https://aeroseal.com/air-duct-sealing-blog/aerobarriers-x1-sealant-becomes-greenguard-gold-certified/.

[88] Source Lawrence Berkeley National Laboratory via Aeroseal

reduced by up to 95%, according to Aeroseal. As one example, Aeroseal was used to reduce the leakage rate in the ductwork of a five-story apartment building in Cambridge, Massachusetts, from greater than 900 cubic feet per minute ("CFM") to an average of 40 CFM – a leakage reduction of approximately 95%.[89] Prior to deploying Aeroseal, the mechanical contractors had used a team of hand sealers employing mastic and tape to attempt to manually seal the ductwork (but the hand sealing was able to bring the leak rate only as low as 900 CFM).[90] The reduction in leak rate Aeroseal obtained was prerequisite to obtaining LEED certification.[91] As a second example, Aeroseal reduced air leakage from ductwork at the Chicago Hilton Hotel (the largest hotel in the world when constructed in the 1920s) from more than 12,000 CFM to approximately 600 CFM (a reduction of approximately 95%).[92] As a final example, Hyundai used Aeroseal to reduce air leakage from ducts at its Southern California headquarters when recently constructed at a cost of $200 million, reducing leakage rates of 20% (which did not meet the code requirement of 5%) to 1%, at a significantly lower cost than alternative leak reduction options.[93]

The reduction in ductwork leak rate by up to 95% typically results in a 20–30% reduction in HVAC energy usage for residential buildings.[94] The HVAC energy savings are even higher for commercial buildings.[95] In commercial buildings, the power needed to operate HVAC systems accounts for between 20–60% of total energy usage, and a 15% reduction in ductwork leakage can reduce fan power input by 40%. The 20–30% or greater reduction in energy usage translates to a 20–30% or greater reduction in GHG emissions associated with that energy usage. According to the EPA, 62% of electricity consumption comes from burning fossil fuels.[96] Much of this energy expenditure is being wasted via leaking air ducts.[97] McKinsey & Company found that sealing air ducts in residential homes offers the greatest potential for reducing home energy usage, and is one of the most cost-effective steps for reducing home energy usage:

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[89] *See* https://aeroseal.com/commercial/case-studies/cambridge-housing-authority/.

[90] *Id*.

[91] *Id*.

[92] *See* https://aeroseal.com/commercial/case-studies/hilton-chicago-hotel/.

[93] *See* https://aeroseal.com/commercial/case-studies/hyundai-u-s-headquarters/.

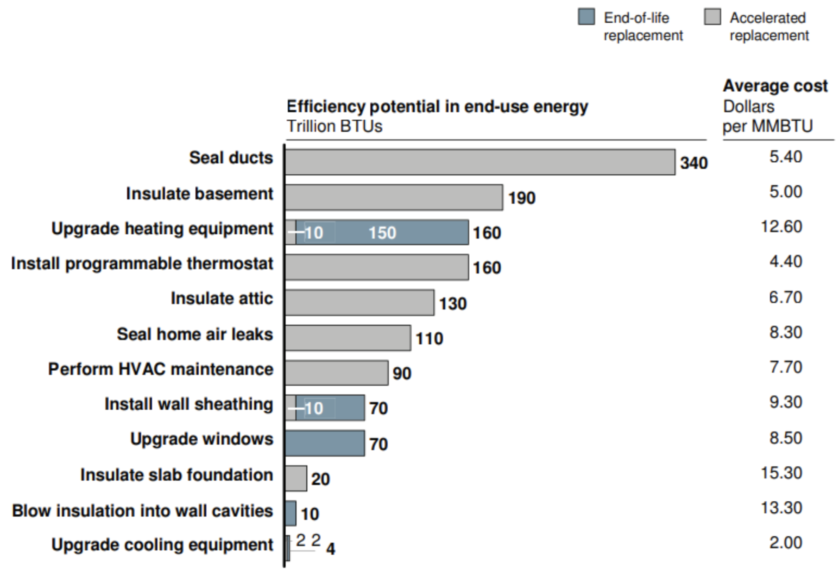
[94] https://aeroseal.com/residential/energy-savings/.

[95] *See* https://aeroseal.com/commercial/energy-consumption/.

[96] United States Environmental Protection Agency, Sources of Greenhouse Gas Emissions, available at: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#t1fn3.

[97] Office of Energy Efficiency & Renewable Energy, About the Commercial Buildings Integration Program, available at: https://www.energy.gov/eere/buildings/about-commercial-buildings-integration-program.

Exhibit 13: Efficiency opportunities in existing non-low-income homes



Source: McKinsey analysis, EIA AEO 2008, RECS, Home Energy Saver model

[98]

The energy wasted through leaking air ducts has a significant financial cost for owners of homes and commercial buildings. As one example, the application of Aeroseal at San Diego's Federal Bureau of Prison (FBOP) detention center, FBOP saves $140,000 in energy costs per year.[99] Aeroseal estimates that a typical residence saves in the range of $850 per year on heating and cooling following application.[100]

Sealing cracks in the HVAC system also improves indoor air quality by preventing outside dust and air pollutants from being pulled into the indoor air. Air pollutants, such as those in vehicle emissions, are a major cause of respiratory and cardiovascular disease in the US.[101] Sealing air ducts prevents unfiltered air from the outdoors from leaking into a building's air ducts, thus preventing dust, vehicle emissions, and other pollutants from seeping indoors (a

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[98] McKinsey & Company, Hannah Choi Grande, et al., Unlocking Energy Efficiency in the US Economy, McKinsey Global Energy and Materials 34 (July 2009), available at: https://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/~/media/204463a4d27a419ba8d05a6c280a97dc.ashx.

[99] Aeroseal, Case Study: Federal Bureau of Prisons Facility, available at: https://aeroseal.com/commercial/case-studies/federal-bureau-of-prisons-facility/.

[100] *See* https://aeroseal.com/residential/energy-savings/.

[101] United States Environmental Protection Agency, Linking Air Pollution and Heart Disease, available at: https://www.epa.gov/sciencematters/linking-air-pollution-and-heart-disease; Brody, Jane E., Air Pollution's Invisible Toll on Your Health (June 28, 2021 5:00 AM EST), available at: https://www.nytimes.com/2021/06/28/well/live/air-pollution-health.html.

particularly significant concern for large commercial buildings in urban areas and residences near freeways). Sealing commercial and residential air ducts could dramatically improve the health of millions of Americans by reducing their exposure to outdoor air pollutants while indoors. Improved indoor air quality can alleviate symptoms of sick building syndrome by 20–50%, asthma by 8–25%, and other respiratory illnesses by 26–75%.[102]

Aeroseal is based in Miamisburg, Ohio. In June 2021, Aeroseal raised $22 million in Series A funding to reduce carbon emissions by 1 gigaton per year.[103]

G. Example Company: enVerid Systems – Ventilation Technology for Commercial HVAC Systems

enVerid has developed sorbent-based air cleaning systems for commercial buildings to clean indoor air and reduce the need for large volumes of outside air to maintain good indoor air quality.[104] Relying on outside air to maintain indoor air quality is energy inefficient as compared to cleaning indoor air, as relying on outdoor air in many climate zones necessitates heating or cooling the air pulled into building from outdoors, which is energy intensive. Additionally, the outside air pulled into buildings often contains air contaminants. Buildings that deploy enVerid's "Sorbent Ventilation Technology" can achieve up to a 40% reduction in HVAC energy usage, improve indoor air quality, and save on costs by downsizing new HVAC systems.

A primary goal of ventilation systems is to maintain good indoor air quality. Most systems are designed to achieve this goal by introducing significant quantities of outside air into the indoor environment.[105] Ventilation systems are traditionally designed to regulate the intake of outdoor air to satisfy guidelines for airflow rates based on the building area (rate per sq. ft.) and the expected number of occupants (rate per person), which are set by a method called the Ventilation Rate Procedure (VRP) which can be found within ASHRAE Standard 62.1[106] and most building codes.[107] This outside air must then be heated or cooled, which requires significant energy usage. The VRP does not give any credit for source control or removal measures (such as cleaning indoor air) when determining minimum ventilation rates.

ASHRAE Standard 62.1 includes a second method for calculating minimum ventilation rates called the Indoor Air Quality Procedure ("IAQP"). The IAQP is a performance-based approach for calculating minimum ventilation rates for acceptable indoor air quality and starts with defining indoor air quality targets and allows the user of the IAQP to account for source

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[102] William J. Fisk, How IEQ Affects Health, Productivity, ASHRAE Journal (May 2002).

[103] Aeroseal, Aeroseal Raises $22 Million to Shrink Carbon Emissions by 1 Gigaton Annually (June 22, 2021), available at: https://aeroseal.com/air-duct-sealing-blog/aeroseal-raises-22-million-to-shrink-carbon-emissions-by-1-gigaton-annually/.

[104] https://enverid.com/

[105] DOE Office of Energy Efficiency & Renewable Energy, Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems (December 2017) ("DOE Commercial HVAC Assessment"), available at: https://www.energy.gov/sites/prod/files/2017/12/f46/bto-DOE-Comm-HVAC-Report-12-21-17.pdf.

[106] *See* https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2.

[107] *Id*.

control and removal measures such as air cleaning before calculating how much outside air is needed to achieve indoor air quality targets. By accounting for the clean air delivered by air cleaning technologies, the amount of outside air required is lowered, which reduces the size requirement for HVAC systems and reduces the heating and cooling load of these systems. According to ASHRAE Standard 62.1, "Although the intake airflow determined using each of these approaches [the VRP or IAQP] may differ significantly… any of these approaches is a valid basis for design."[108] The IAQP may be preferred when the user prioritizes better indoor air quality, the outside air is contaminated, or a more cost-effective ventilation solution is desired.[109]

enVerid's Sorbent Ventilation Technology is one of the only air cleaning technologies on the market able to remove all the contaminants of concern that have been identified by ASHRAE Standard 62.1 and the US Green Building Council. enVerid Sorbent Ventilation Technology has been designed to capture gases like carbon dioxide (CO_2), ozone, and more than 250 types of volatile organic compounds (VOCs), including formaldehyde, without producing any byproducts. Lower levels of CO_2 and VOCs have been shown to correlate with improved cognitive function.[110] The sorbent cartridges differ from many traditional fiber filter indoor air pollution controls, which are limited in application to solid particles.

In addition to removing indoor air contaminants which are generated indoors, another benefit of replacing outside air with cleaned indoor air is a reduction in the intake of outside air polluted by wildfires, highways and airports, industrial operations, and other sources. More than 40% of Americans live with unhealthy outdoor air.[111]

Combining enVerid's "HLR" modules, which use Sorbent Ventilation Technology to clean indoor air, with the IAQP can reduce outside air requirements by up to 85%.[112] This in turn can deliver annual HVAC energy savings of up to 40%.[113] Reducing the amount of outside air that must be pulled in to maintain indoor air quality also reduces the total load on the HVAC system. This in turn enables the downsizing of new HVAC systems and saves energy, reduces carbon emissions, and extends equipment life.

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[108] ASHRAE Standard 62.1–2019, Section 6.1.

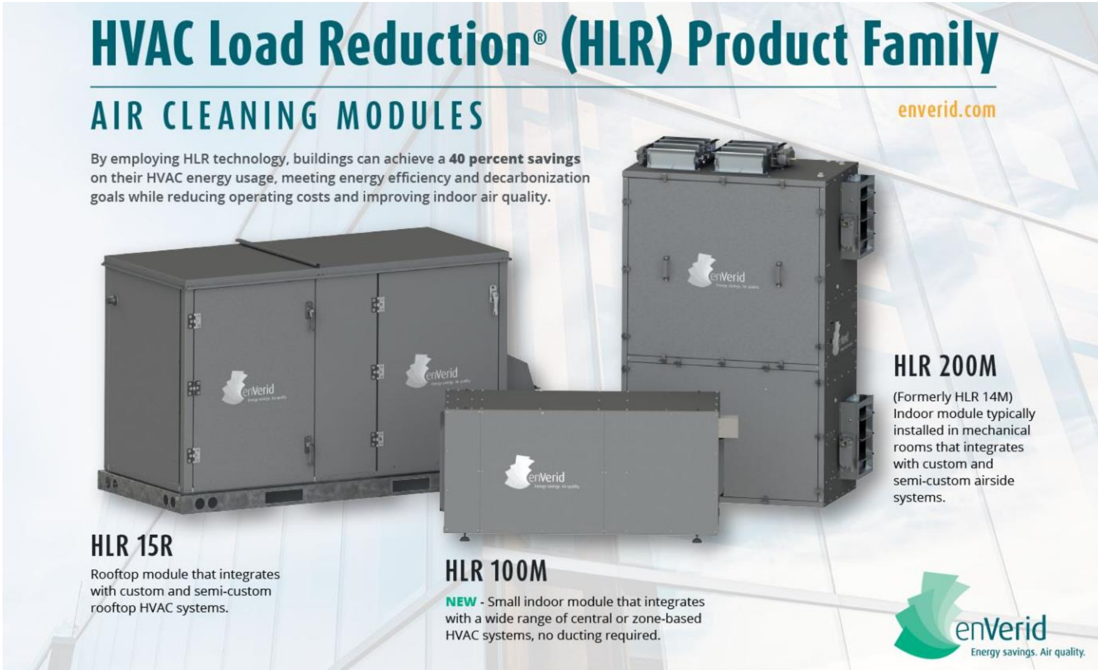
[109] ASHRAE Standard 62.1 User's Manual (June 2021).

[110] https://www.hsph.harvard.edu/news/press-releases/office-air-quality-may-affect-employees-cognition-productivity/.

[111] State of the Air Report from the American Lung Association, available at: https://www.lung.org/research/sota/key-findings#:~:text=The%20%22State%20of%20the%20Air,air%20is%20not%20shared%20equally.

[112] DOE Commercial HVAC Assessment at 43.

[113] *Id.*



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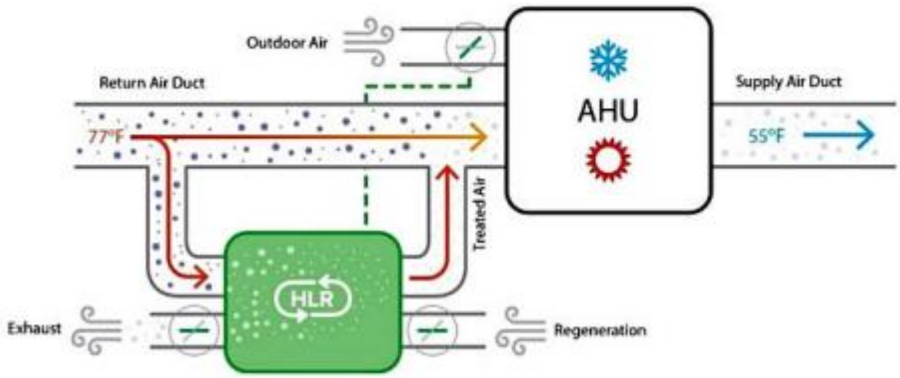

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enVerid estimates that deploying HLR technology globally has the potential to reduce more than 300 million tons of carbon emissions each year by 2050.

Payback periods based on HVAC energy savings for target applications range from zero to five years depending on climate zone, operating hours, energy costs, building-specific installation costs, and utility incentives.[116] Each HLR module delivers cost savings of up to $25,000 by downsizing HVAC equipment by up to 20 tons of cooling load and 200 MBH of

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[114] Source: enVerid

[115] Source: enVerid

[116] DOE Commercial HVAC Assessment at 45.

heating load. System maintenance is limited, consisting primarily of annual cartridge replacement and sensor calibration.[117]

enVerid's Sorbent Ventilation Technology has been used in office buildings, schools, and warehouses. As one example, an enVerid system installed on the University of Miami campus resulted in a reduction in HVAC outside air usage of 75% and an HVAC energy savings of 36% (while improving indoor air quality and significantly reducing operational cost).[118] DOE's assessment of field studies, including those conducted with the DOE and the US General Services Administration, found similar energy savings at other sites operating enVerid systems.[119]

enVerid is based in Westwood, Massachusetts. enVerid technology has been funded and tested by DOE.[120] In April 2020, enVerid raised a $20 million Series B round of financing.[121] In September 2021, Daikin, the world's largest HVAC manufacturer, announced the industry's first packaged total-air-quality system, which combines the enVerid Sorbent Ventilation Technology with a configurable rooftop HVAC system. According to Daikin, "Adding enVerid SVT to this packaged system delivers superior air quality, and the ability to cut energy use and carbon emissions. It changes how buildings can be designed to further both IAQ and decarbonization efforts."[122]

H. Example Company: 75F – Smart Control for Commercial Building Energy Efficiency

75F designs smart controls for commercial building energy efficiency to reduce HVAC, boiler, and lighting energy usage by 30–50%.[123] 75F serves the office, retail, and restaurant markets.

75F uses sensors and controllers, including thermostats that monitor not just temperature but also light, humidity, sound, occupancy, CO_2, VOCs, and supplied air temperature and smart nodes that monitor variable air volume ("VAV") boxes, damper and valve actuators, pumps, variable frequency drives, lighting circuits, and other equipment. 75F's software controls all manner of building mechanical equipment, including remote terminal units, air handlers, and other equipment.

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[117] DOE Commercial HVAC Assessment at 43.

[118] *See* University of Miami Saves $19,500 HVAC Energy Annually, available at: https://enverid.com/resources/case-studies/annual-hvac-savings-at-u-miami-health/.

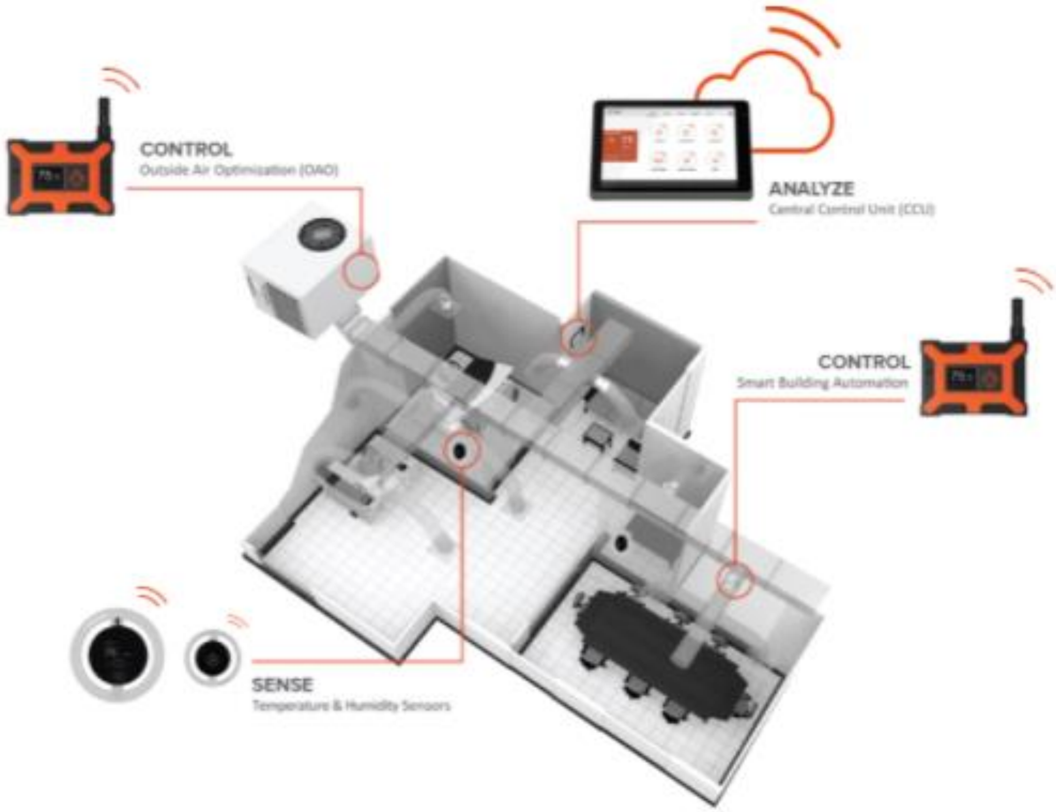
[119] DOE Commercial HVAC Assessment at 44.

[120] DOE, enVerid Systems – HVAC Load Reduction, available at: https://energy.gov/eere/buildings/downloads/enverid-systems-hvac-load-reduction.

[121] 41 GSA. 2017. "Smart Scrubbers for HVAC Load Reduction." August 2017. Available at: https://www.finsmes.com/2020/04/enverid-systems-secures-20m-in-series-b-funding.html.

[122] https://www.daikinapplied.com/news/news/daikin-applied-boosts-iaq-with-upgraded-rebel-applied-rooftop-heating-and-cooling-system.

[123] *See* 75F, available at: https://www.75f.io/.



[124]

Capturing a vast amount of data from its smart sensors, 75F's automations system analyzes, predicts, and controls building energy usage. The system is intended to ensure that the HVAC system runs only when, where, and as much as is needed, to eliminate hot spots and minimize energy usage. 75F's advanced lighting technology tracks outdoor lighting conditions – sunrises, sunsets, and cloud cover conditions – to similarly optimize lighting.

One example of the energy savings 75F has achieved is a 38,000 square-foot Mercedes Benz research center, where HVAC and lighting energy has decreased by 25%.[125] Building occupants also reported greater levels of comfort as a result of greater control of temperature and improved indoor air quality.[126] As a second example, at MapleTree Investments' 13-acre global technology park, which was LEED Gold certified, 75F's installation of smart sensors and controls automated the HVAC system, delivering a 19.5% reduction in HVAC (and lighting)

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[124] Source: 75F

[125] *See* EnVerid, Mercedes-Benz Case Study, available at: https://www.75f.io/results/client-results/building-automation-system-case-studies.

[126] *Id.*

energy usage.[127] Further, the employee complaints about uneven building temperatures that originally led MapleTree to install the 75F system were resolved.[128]

75F is based in Minneapolis, Minnesota. It raised $28 million in funding in July 2021.[129]

I. Example Company: Dandelion Energy – Home Geothermal Energy Systems

Dandelion Energy is a home geothermal energy company serving the Northeastern United States.[130] Geothermal energy systems harness subsurface energy to provide heating and cooling, allowing homeowners to stop the use of natural gas, propane, or fuel oil combustion for home heating, and to reduce or eliminate air conditioner usage, avoiding the emissions that would be associated with fuel combustion or air conditioner electricity usage.

Geothermal heating and cooling systems are essentially heat transfer systems which make use of the fact that the temperature of the earth 10 feet below ground is 55 degrees Fahrenheit, year-round and no matter the ambient temperature. In other words, the subsurface is generally warmer than ambient temperature in the wintertime and cooler than ambient temperature in the summertime.

Dandelion uses closed loop pipes to transfer heat from the subsurface into homes when it is cold outside, and to transfer heat from homes into the subsurface when it is warm outside.

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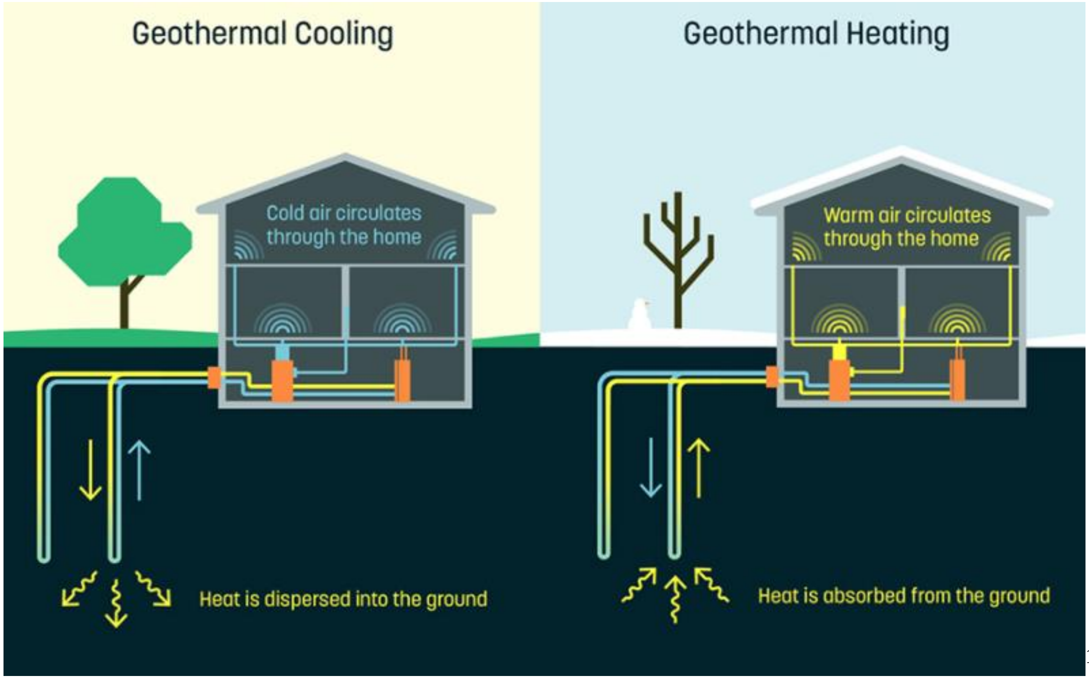
[127] *See* EnVerid, MapleTree Case Study, available at: https://www.75f.io/results/client-results/building-automation-system-case-studies.

[128] *Id*.

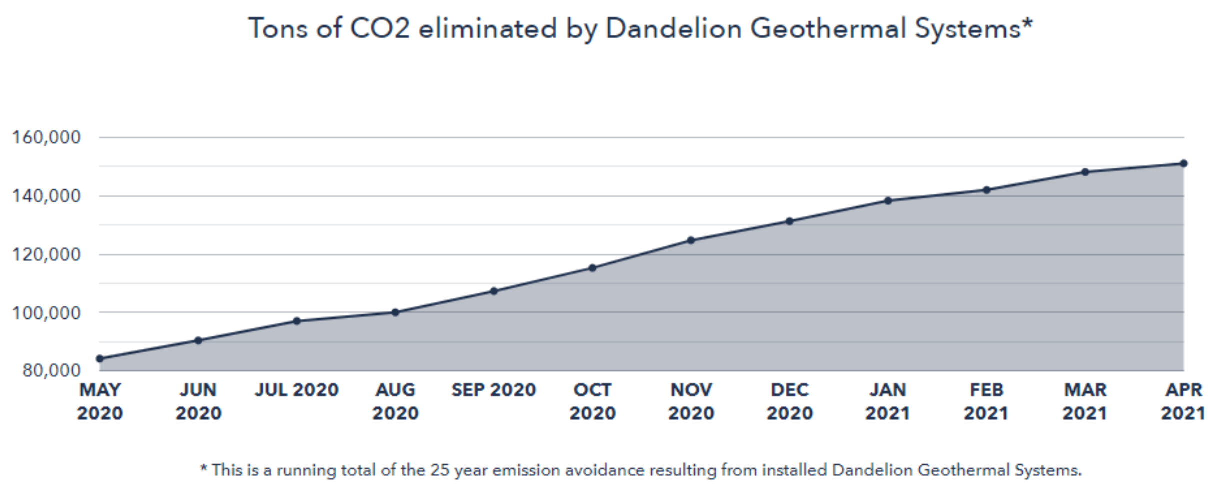
[129] https://www.finsmes.com/2021/07/75f-raises-28m-in-funding.html.

[130] www.dandelionenergy.com



[131]

Home geothermal systems generate no GHG emissions. This is in contrast to using traditional energy sources for heating homes, such as electricity from the grid, natural gas, or heating oil. A Dandelion system achieves a 60% reduction in a home's GHG emissions when switching from natural gas, an approximately 65% reduction when switching from propane, and an approximately 80% reduction when switching from fuel oil.[132]



[133]

[131] Source: Dandelion Energy

[132] Dandelion Energy, https://dandelionenergy.com/environmental-impact.

[133] Source: Dandelion Energy

Geothermal energy has an added safety advantage: unlike systems that rely on natural gas delivery via pipeline, there is reduced risk of a geothermal system causing explosions. Further, the risk of carbon monoxide poisoning from fuel-burning appliances is not a risk of geothermal energy systems.

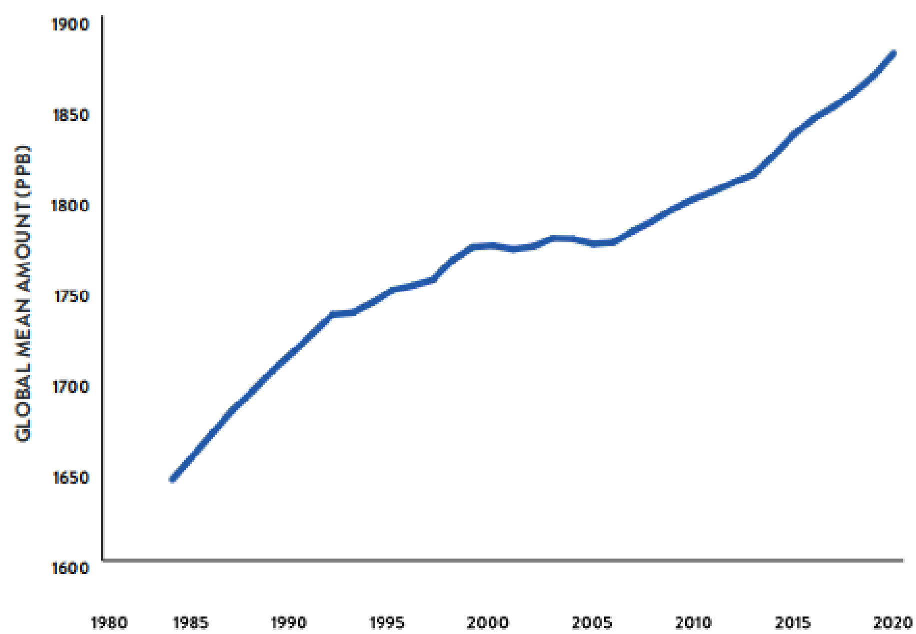
Dandelion's systems also have a cost advantage over traditional heating and cooling methods. Dandelion systems cost approximately $18,000 to $25,000 to install, and operational costs that are constant over time (in contrast to traditional heating and cooling systems which rely on fluctuating natural gas, oil, and electricity prices).

Dandelion is based in New York. Dandelion was originally conceived of at X, the innovation lab run by Alphabet (the parent of Google).

IV. OIL AND GAS PRODUCTION METHANE LEAKS

"When you look at the future, the Achilles heel of the gas industry is the methane emissions." – Fatih Birol, Executive Director of the International Energy Agency (September 2019)[134]

Methane is a potent GHG, with a warming potential more than 80 times higher than that of carbon dioxide over a 20-year period.[135] Over the last 250 years, the concentration of methane in the atmosphere has increased by 167%, and in recent years methane concentrations have been increasing at a faster rate than at any point in history.[136] Natural gas systems are one of the main contributors to methane emissions. In 2019, they were the second-largest source of anthropogenic methane emissions in the US. Reducing fugitive methane emissions from the oil and gas industry is an enormous opportunity for reducing overall GHG emissions. Two technologies key to achieving this goal are advanced (1) methane leak monitoring and (2) leakless valves.



<u>Global mean methane amount, 1984–2019, parts per billion</u>[137]

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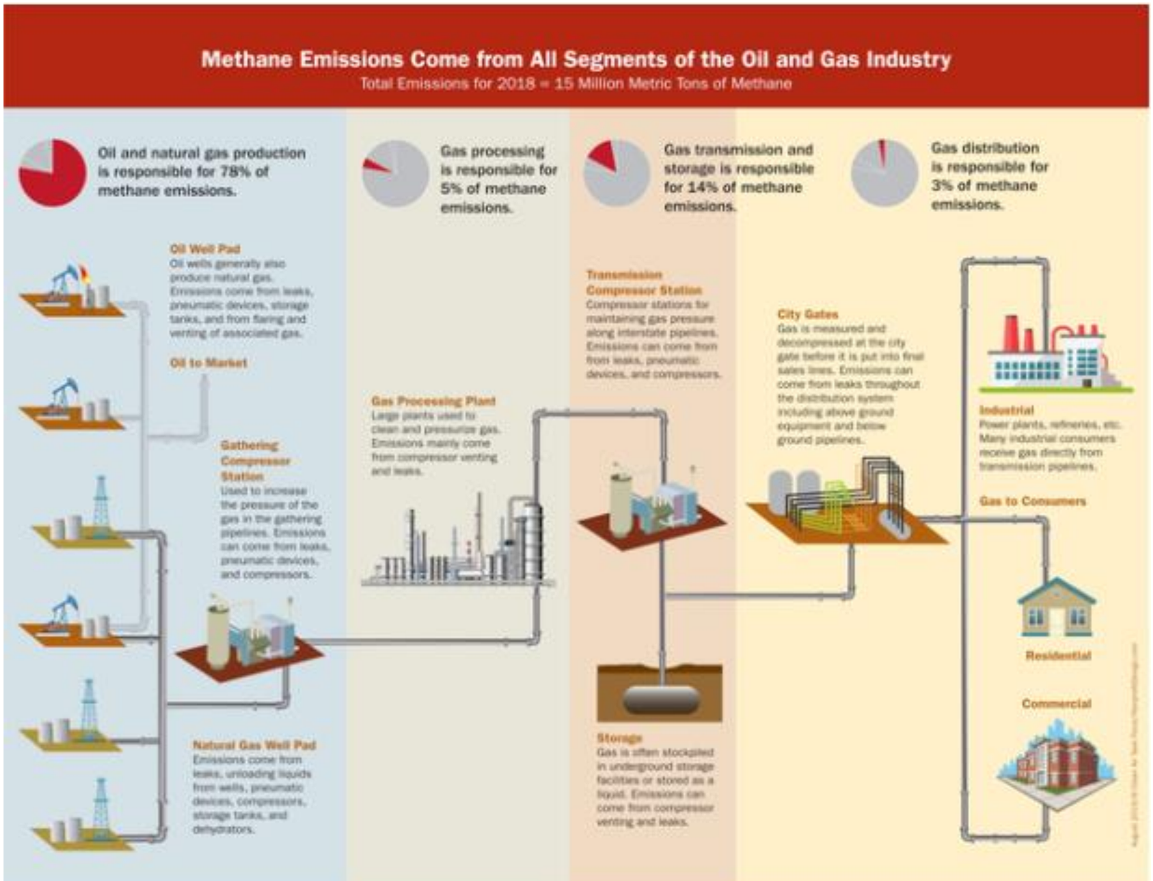
[134] Institute for Energy Economics and Financial Analysis, *IEA's Birol: Methane leaks, flaring are 'Achilles heel' for LNG industry*, https://ieefa.org/ieas-birol-methane-leaks-flaring-are-achilles-heel-for-lng-industry/ (last visited May 5, 2021).

[135] *See*, US EPA, *Understanding Global Warming Potentials*, https://www.epa.gov/ghgemissions/understanding-global-warming-potentials (last visited April 23, 2021).

[136] US EPA GHG Inventory at ES-15.

[137] Climate and Clean Air Coalition and United Nations Environment Programme, *Global Methane Assessment* (2021), available at: https://www.ccacoalition.org/en/resources/global-methane-assessment-full-report.



Overview of Methane Emissions from Oil and Gas Production[138]

A. Overview of Oil and Gas Production Fugitive Emissions

Methane accounts for approximately 10% of US and 16% of global GHG emissions from human activities, when taking into account the relatively high GWP of methane.[139] Leaks from oil and gas wells, pipelines, and other facilities have contributed to a spike in methane emissions, accounting for more than 5% of global energy-related GHG emissions.

Methane emissions from natural gas systems and petroleum systems in the US (when aggregated) were 196.7 MMT CO_2 Eq. in 2019.[140] Natural gas system methane emissions decreased by approximately 15% since 1990, largely due to a decrease in emissions from

[138] Source: Clean Air Task Force, https://www.catf.us/educational/us-oil-gas/.

[139] US EPA, Overview of Greenhouse Gases, available at: https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane and Global Greenhouse Gas Emissions Data, available at: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data.

[140] US EPA GHG Inventory at 2–16.

distribution, transmission and storage, processing, and exploration.[141] The decrease in distribution-related emissions is largely due to reducing leaks from pipelines and distribution stations, and the decrease in transmission and storage emissions is largely due to reduced compressor station emissions (including emissions from compressors and leaks).[142]

However, over the past 30 years, emissions from the natural gas production segment increased.[143] A series of studies coordinated by Environmental Defense Fund ("EDF") and more than 140 research and industry experts from 40 institutions and 50 companies indicated that the US oil and gas system leaked on average 2.3% of all the gas it produced, 60% more than the leakage rate reported by the EPA.[144] Field measurements from the Permian Basin, which extends from West Texas into southeastern New Mexico and accounts for 30% of US oil production and 10% of the country's gas output, reportedly indicated that wells in the Permian were leaking enough gas to supply seven million homes in Texas.[145]

Apart from its implications for climate change, fugitive methane emissions contribute to ozone emissions, and co-pollutants emitted alongside methane include VOCs.

B. Technologies for Reducing Oil & Gas Sector Fugitive Emissions

A 2021 International Energy Agency report concluded that reducing methane emissions from oil and gas operations is one of the most cost-effective and impactful actions that governments can take to achieve climate goals.[146] A significant share of emissions may be abated at no net cost, because the value of captured methane is sufficient to cover the cost of abatement, the IEA found.

Although it makes economic sense for companies to implement such measures on their own, experts such as the IEA often conclude that government action may be needed to force or incentivize the implementation of abatement technologies.[147] Indeed, companies have called on the US government to tighten restrictions on GHG emissions from oil and gas production.[148]

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[141] *Id.*

[142] *Id.*

[143] *Id.*

[144] *See e.g.*, Benjamin Storrow, *Methane Leaks Erase Some of the Climate Benefits of Natural Gas*, Scientific American (May 5, 2020), https://www.scientificamerican.com/article/methane-leaks-erase-some-of-the-climate-benefits-of-natural-gas/#:~:text=Methane%2C%20the%20primary%20component%20of,being%20released%20into%20the%20atmosphere.

[145] *Id*.

[146] IEA, *Driving Down Methane Leaks from the Oil and Gas Industry* (January 2021), https://www.iea.org/reports/driving-down-methane-leaks-from-the-oil-and-gas-industry.

[147] *Ibid.*

[148] Ron Bousso, *Shell urges Trump White House to tighten methane leak rules*, Reuters (March 12, 2019), https://www.reuters.com/article/us-ceraweek-energy-emissions/shell-urges-trump-white-house-to-tighten-methane-leak-rules-idUSKBN1QT2DT.

A 2014 ICF report indicated that the US oil and gas industry could cut projected methane emissions by 40% at an average annual cost of less than one cent on average per thousand cubic feet of produced natural gas by adopting available emissions-control technologies and operating practices.[149]

Methane leaks from the oil and gas industry may be reduced through the implementation of methane leak monitoring technologies and advanced valve technologies aimed at preventing leaks. There are a wide variety of technologies both currently available and in development to effectively monitor for methane leaks, allowing for swift remedial action, including on-site leak surveys using optical gas imaging, deployment of passive sensors at individual facilities or mounted on ground-based work trucks, and in situ remote-sensing approaches using tower networks, aircraft, or satellites.[150] In addition, improvements to gas containment systems to prevent fugitive emissions, with a specific focus on valve technology, can reduce the risk of leaks.[151]

1. Methane Leak Monitoring

The early detection of leaks is essential to abating fugitive emissions. A number of different technologies are used or in development to monitor methane levels within the oil and gas industry that pinpoint leaks in pipelines and facilities.

Monitoring traditionally has necessitated active use of hand-held devices, airplanes with specialized monitoring equipment, or, more recently, drones.[152] These active techniques require human oversight, are expensive, are dependent upon weather conditions and operator skill, do not provide a sense as to the size of the leak, and cannot provide continuous monitoring.[153]

To address these problems, researchers and companies have been working to develop passive, autonomous monitoring technology that can be deployed at operating sites and along gas transportation lines to provide automatic alerts with more precision as to leak size, all at reduced

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[149] ICF International, *Economic Analysis of Methane Emission Reduction Opportunities in the US Onshore Oil and Natural Gas Industries* (March 2014), https://www.edf.org/sites/default/files/content/icf_methane_exec_summary_with_url.pdf.

[150] *See* Jonathan Mingle, *Methane Detective: Can a Wave of New Technology Slash Natural Gas Leaks?*, Yale Environment 360, (October 31, 2019), https://e360.yale.edu/features/methane-detectives-can-a-wave-of-new-technology-slash-natural-gas-leaks; Ramon A. Alvarez, et al., Science Magazine, *Assessment of methane emissions from the US oil and gas supply chain* (July 13, 2018), https://science.sciencemag.org/content/361/6398/186.full?ijkey=42lcrJ/vdyyZA&keytype=ref&siteid=sci.

[151] *See* National Resource Defense Council, *Leaking Profits: The US Oil and Gas Industry Can Reduce Pollution, Conserve Resources, and Make Money by Preventing Methane Waste*, (March 2012), https://www.nrdc.org/sites/default/files/Leaking-Profits-FS.pdf.

[152] *See, e.g.*, US EPA, *Leak Detection Technology & Methodology*, (June 7, 2018), https://www.epa.gov/natural-gas-star-program/leak-detection-technology-and-methodology; NASA, *Methane Near IR Tunable Diode Laser Absorption Spectrometer*, https://airbornescience.nasa.gov/instrument/NOAA_CH4 (last visited April 23, 2021).

[153] *See* Jonathan Mingle, *Methane Detective: Can a Wave of New Technology Slash Natural Gas Leaks?*, Yale Environment 360, (October 31, 2019), https://e360.yale.edu/features/methane-detectives-can-a-wave-of-new-technology-slash-natural-gas-leaks.

cost.[154] These technologies largely focus on laser absorption spectroscopy (also known as infrared absorption spectroscopy), a technique to measure the amount of light absorbed in ambient air and identify clouds of methane gas that would otherwise be invisible.[155] Such technology can reduce industry methane emissions by 18% overall, and create a return on investment of 400 to 600% the cost within a year as valuable resources are kept from escaping into the atmosphere.[156]

2. Advanced Valve Technology

Valves are essential to production, gathering, processing, transmission, and distribution of natural gas. However, they are a frequent source of gas leaks.[157]

The commercial valve industry has worked to identify new technologies to reduce fugitive emissions from gas systems.[158] The challenge has been the highly pressurized nature of gas extraction and transportation. Different companies are developing different technologies to provide the best seals at connection points to both handle the constant pressure and prevent foreign substances from compromising the system.[159] Severe service conditions drive the need for development of valve coatings, which aid in preventing wear on the system which otherwise would create weak points for highly pressurized methane to escape.[160] As valve manufacturing technology improves and more methane systems are upgraded, leaks are reduced, leading to lower fugitive emissions rates, with a reduced contribution to both atmospheric GHGs and local methane exposures, all the while contributing to increased profits through commodity retention.

We provide overviews below of two companies deploying technologies for detecting and eliminating fugitive emissions from the oil and gas sector.

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[154] *See, e.g.*, *ExxonMobil Field Tests New Methane Leak Detection Systems*, Journal of Petroleum Technology, (April 13, 2020), https://jpt.spe.org/exxonmobil-field-tests-new-methane-leak-detection-systems; Stephen Whitfield, *Program Aims To Slash Cost of Methane Sensor Systems*, Journal of Petroleum Technology, (January 16, 2018), https://jpt.spe.org/program-aims-slash-cost-methane-sensor-systems; *Pathways for Alternative Compliance*, Environmental Defense Fund, (April 2019), https://www.edf.org/sites/default/files/documents/EDFAlternativeComplianceReport_0.pdf.

[155] *See* US EPA, *Natural Gas STAR Program: Infrared (IR) Methane Videos*, https://www.epa.gov/natural-gas-star-program/videos-about-methane-emissions-oil-and-gas-industry (last visited April 23, 2021).

[156] *See* National Resource Defense Council, *Leaking Profits: The US Oil and Gas Industry Can Reduce Pollution, Conserve Resources, and Make Money by Preventing Methane Waste*, (March 2012), https://www.nrdc.org/sites/default/files/Leaking-Profits-FS.pdf.

[157] *See*, US EPA, *Primary Sources of Methane Emissions*, https://www.epa.gov/natural-gas-star-program/primary-sources-methane-emissions (last visited April 23, 2021).

[158] *See, e.g.*, John V. Ballun, *The Valve Industry's Role in Climate Change*, Valve Magazine, (Jan. 20, 2017), https://www.valvemagazine.com/magazine/sections/features/8152-the-valve-industry-s-role-in-climate-change.html.

[159] *See, e.g.*, ValvTechnologies, *Upstream Oil & Gas: Critical Service Valve Applications for the Upstream Oil and Gas Industry*, http://www.valv.com/industries/oil-gas-upstream/ (last visited April 23, 2021); Baker Hughes, *Emissions Management*, https://www.bakerhughes.com/emissions-management (last visited April 23, 2021).

[160] *Ibid.*

C. Example Company: ValvTechnologies' Leak-Proof Valves

ValvTechnologies is pioneering the development and manufacture of metal seated, zero-leakage severe service isolation solutions for the oil and gas industry (as well as other industries where severe service valves are needed, such as the nuclear power and chemical processing industries).[161]

ValvTechnologies valves are guaranteed to have absolute zero-leakage for four years in steam and power applications. Zero-leakage is defined as no detectable leakage of gas or liquid for a period of three minutes or greater. While other systems have allowable leakage between 92.5 gallons and 608.5 gallons per year, ValvTecnologies' allowable leakage is 0.[162]

ValvTechnologies uses an innovative method to prevent leakage, departing from the industry norm of traditional gate and plug valves. Rather than the traditional loose seat design, ValvTechnologies products utilize an integral design, providing a stable platform onto which the ball is constantly loaded with high force, making it impossible to trap solids between the ball and seat. When the ball is in the open position, the seats are protected from the substance flow. The integral seat also eliminates the potential for leakage between a loose seat and valve body.

The ball and integral seat are both coated with chrome or tungsten carbide using ValvTechnologies' proprietary high velocity oxygen fuel (HVOF) coating process called RiTech®, or Robotically Integrated Technology. This unique approach increases surface hardness far beyond that of conventional weld-overlay hardening techniques. The increased surface hardness makes the sealing surfaces impervious to erosion and abrasion, a constant threat in the high-pressure, high-temperature environment of oil and gas industry process conditions. A high-strength Belleville® spring also provides force to load the ball into the seat, solving many of the typical problems related to buildup and corrosion in trunnion bearings, and eliminates free space between the ball and seat.

ValvTechnologies has proven success in downstream and chemical processing, upstream oil and gas, and critical power industries. ValvTechnologies products are installed around the world, from Texas and Minnesota to Malaysia, Kazakhstan, Belarus, and India.[163]

ValvTechnologies is located in Houston, Texas and is the global leader in design and manufacturing of severe service, zero-leakage valves. ValvTechnologies has seven companies in its corporate family, employs a total of 488 individuals across all locations, and generates more than $85 million in sales.[164]

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[161] http://www.valv.com/

[162] *See* ValvTechnologies, *Zero-Leakage*, http://www.valv.com/zero-leakage/ (last visited April 26, 2021).

[163] *See* ValvTechnologies, *Success Stories*, http://info.valv.com/valvtechnologies-success-stories (last visited April 26, 2021).

[164] *See* ValvTechnologies Inc., *Company Profile*, Dun & Bradstreet Business Directory, https://www.dnb.com/business-directory/company-profiles.valvtechnologies_inc.c144fd041f4fae006e6b5a53502bfa57.html (last visited April 26, 2021).

D. Example Company: Aeris Technologies Advanced Methane Sensor

Aeris Technologies[165] is a startup company based in Hayward, California, producing fast, portable technologies to detect methane leaks that provide part-per-billion measurements in real time. In partnership with the Los Alamos National Laboratory's Richard P. Feynman Center for Innovation, Aeris Technologies has developed a small methane sensor that could be attached to almost any gas and wind sensor and a corresponding algorithm to estimate the location and size of leaks anywhere inside roughly 100 meters (called the Autonomous, Low-cost, Fast Leak Detection System or "ALFaLDS").

Aeris Technologies' autonomous system utilizes artificial neural networks and dispersion models to quantify and locate leaks. The system looks for correlations between methane levels gathered at a sensor and the wind direction at a specific time. The neural network collects those correlations over time to pinpoint leaks.[166]

Aeris Technologies estimates that ALFaLDS could reduce methane emissions by up to 90% through early detection. Currently available methods to detect methane leaks, such as infrared scanners, are cost-prohibitive at scale. In contrast, Aeris Technologies' ALFaLDS is a fraction of the size and cost of other laser-based analyzers in its category, and could be attached to existing sensors or to cars or trucks because it can be operated at highway speed. Further, Aeris Technologies' proposed new technology raises the possibility that a network of methane-sniffing sensors at oil and gas facilities could be used to generate real-time methane leak maps, giving firms the ability to dispatch technicians to stanch leaks almost as soon as they occur.[167]

Aeris Technologies has also developed a portable mid-IR laser gas sensor. This sensor combines a "real-time laser absorption spectrometer with built-in GPS capability to produce the world's smallest, most powerful natural gas leak mapping tool" that is able to discriminate natural gas "from other biogenic sources such as landfill gas, cattle operations, sewer gas, and permafrost."[168] The portable analyzers utilize a compact, pressure stabilized sensor core to achieve high sensitivity and low drift, significantly reducing or eliminating calibration requirements in many field applications.[169]

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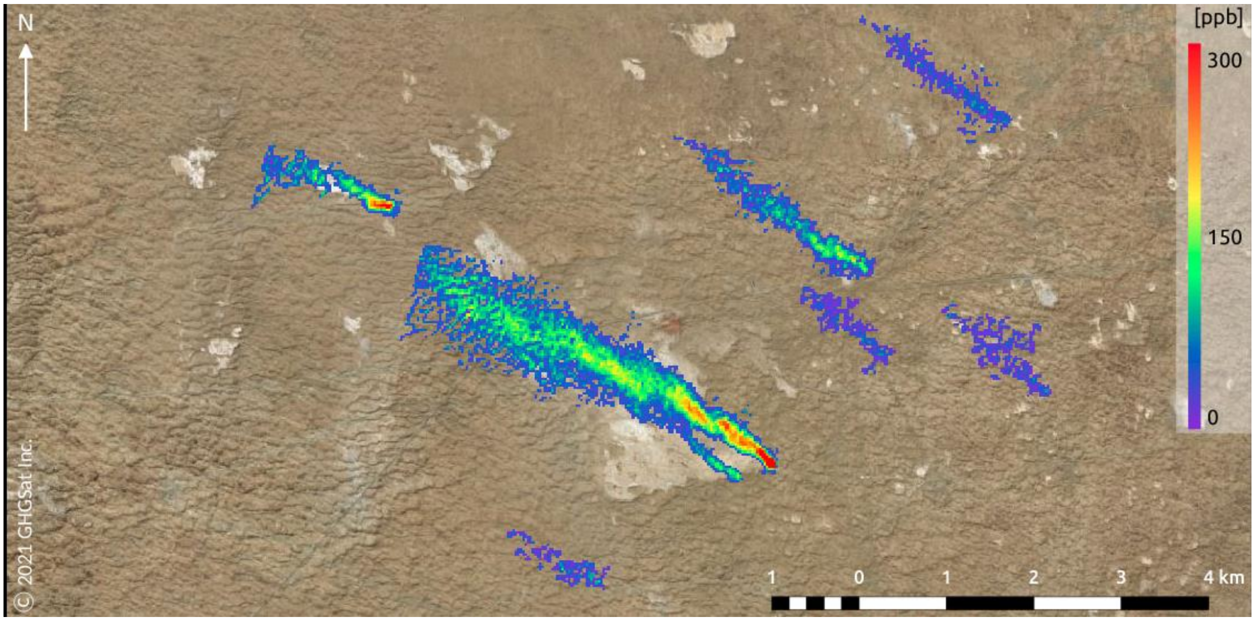
[165] https://aerissensors.com/technology/

[166] Stephen Whitfield, *Program Aims To Slash Cost of Methane Sensor Systems*, Journal of Petroleum Technology, (January 16, 2018), https://jpt.spe.org/program-aims-slash-cost-methane-sensor-systems (last visited April 26, 2021).

[167] *See* Aeris Technologies, *Aeris on forbes.com: Los Alamos Scientists Say Their New Technology Could Cut Methane Emissions by 90%*, https://aerissensors.com/2020/11/23/aeris-on-forbes-com-los-alamos-scientists-say-their-new-technology-could-cut-methane-emissions-by-90/ (last visited April 26, 2021).

[168] *See* Aeris Technologies, *Locate Natural Gas Leaks with Unmatched Sensitivity, Ease-of-Use, and Thermogenic v. Biogenic Discrimination*, https://aerissensors.com/mira-pico-mobile-lds/ (last visited April 26, 2021).

[169] *See* Aeris Technologies, *Aeris Pico Analyzer: the Worlds' First Truly Portable Mid-IR Laser Gas Sensor*, https://aerissensors.com/pico-series/ (last visited April 26, 2021).

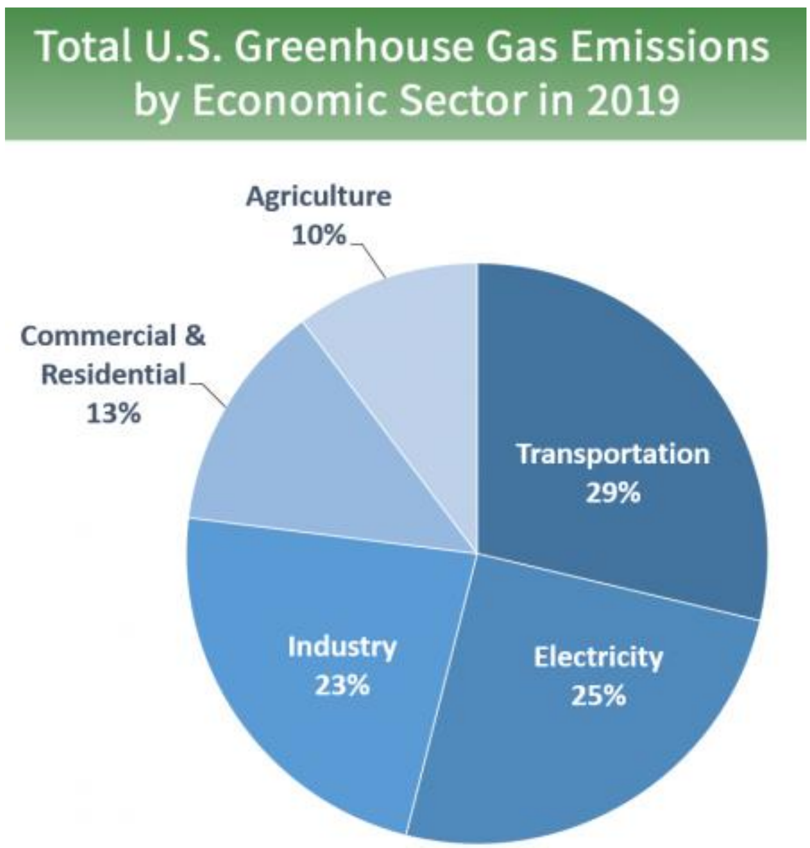


As one example of advanced leak monitoring technology, the company GHGSat has been operating high-resolution GHG monitoring satellites since 2016. This GHGSat image shows methane leaks in central Turkmenistan in February 2021, with an estimated emissions rate of up to 10,000 kg of methane per hour.[170]

[170] Naureen S. Malik, *New Climate Satellite Spotted Giant Methane Leak as It Happened*, Bloomberg, (February 12, 2021), https://www.bloomberg.com/news/articles/2021-02-12/new-climate-satellite-spotted-giant-methane-leak-as-it-happened (last visited May 2, 2021).

V. MOVEMENT OF GOODS AND PEOPLE BY AUTOMOBILES, TRUCKS, AND TRAINS

The transportation sector, which includes the movement of people and goods by cars, trucks, trains, ships, airplanes, and other vehicles, is the single greatest contributor to GHG emissions in the US. Although much of the focus on reducing emissions from the transportation sector is on fuel switching and fuel efficiency, there are other technologies with significant potential to reduce transportation-related GHG emissions. We highlight two: (1) light-weighting of cars, trucks, and airplanes using advanced materials; and (2) additive manufacturing, or 3D printing. Light-weighting transportation vehicles reduces their fuel consumption and, by extension, their GHG emissions. Additive manufacturing has the potential to co-locate manufacturing sites close to consumers, reducing the need for transportation across the country or across the globe, and eliminating the GHG emissions associated with such transportation.



<u>Sources of US GHG Emissions in 2019</u>[171]

A. Overview of Transportation Sector GHG Emissions

The transportation sector is critical to the economy. In 2019, the transportation sector

[171] US EPA, Inventory of Greenhouse Gas Emissions and Sinks 1990–2019, EPA 430-R-21-005 (April 2021).

contributed $1.3 trillion (approximately 6%) to an enhanced US GDP of $21.8 trillion.[172] Trucking contributed the largest amount, at $368.9 billion, and household transportation contributed $359.5 billion.

1. Nature of Transportation Sector GHG Emissions

The majority of GHG emissions from transportation are CO_2 emissions resulting from the combustion of petroleum-based products, such as gasoline and diesel, in internal combustion engines.[173] The largest sources of transportation-related GHG emissions include passenger cars, medium- and heavy-duty trucks, and light-duty trucks, including sport utility vehicles, pickup trucks, and minivans, which together account for more than half of the emissions from the transportation sector. The remaining greenhouse gas emissions from the transportation sector come from other modes of transportation, including commercial aircraft, ships, boats, and trains, as well as pipelines and lubricants. In addition, relatively small amounts of methane and nitrous oxide are emitted during fuel combustion, and a small amount of hydrofluorocarbon emissions are emitted due to the use of mobile air conditioners and refrigerated transport.

2. Magnitude of Transportation Sector GHG Emissions

In 2019, GHG emissions from transportation accounted for about 29% of total US GHG emissions, making transportation the largest contributor to US greenhouse gas emissions. The largest sources of transportation-related GHG emissions were: passenger cars (41%); freight trucks (23.2%); light-duty trucks, which include sport utility vehicles, pickup trucks, and minivans (17.3%); commercial aircraft (6.9%); pipelines (2.8%); other aircraft (2.6%); ships and boats (2.2%); and rail (2.1%).[174]

In terms of the overall trend, from 1990 to 2019, total transportation emissions have increased due, in large part, to increased demand for travel. The number of vehicle miles traveled (VMT) by light-duty motor vehicles (passenger cars and light-duty trucks) increased by 48% from 1990 to 2019 as a result of a confluence of factors including population growth, economic growth, urban sprawl, and periods of low fuel prices. Between 1990 and 2004, average fuel economy among new vehicles sold annually declined, as sales of light-duty trucks increased. Starting in 2005, average new vehicle fuel economy began to increase while light-duty VMT grew only modestly for much of the period. Average new vehicle fuel economy has improved almost every year since 2005, slowing the rate of increase of CO_2 emissions, and the truck share is about 56% of new vehicles in model year 2019.

Globally, heavy-duty vehicle (HDV) energy consumption and tailpipe CO_2 emissions have increased by 2.6% per year since 2000, with trucks responsible for more than 80% of this growth. Rising emissions and energy use are driven primarily by greater economic activity and

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[172] US Bureau of Transportation Statistics, Contribution of Transportation to the Economy, https://data.bts.gov/stories/s/smrm-36nv.

[173] US EPA, Sources of Greenhouse Gas Emissions: Transportation Sector Emissions, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

[174] US EPA, Inventory of US Greenhouse Gas Emissions and Sinks, 1990–2019, at 128, https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-main-text.pdf.

increased demand for goods, which translates into more delivery and more trucking activity.[175] In addition, CO_2 emissions from aviation have risen rapidly over the past two decades, reaching nearly 1 Gt in 2019, or about 2.8% of global CO_2 emissions from fossil fuel combustion.[176] Since 2000, commercial passenger flight activity has grown by about 2.5-fold (5% per year), while CO_2 emissions rose by 50% (2% per year), due to operational and technical efficiency measures adopted by commercial airlines, including new aircraft purchases. The energy intensity of commercial passenger aviation has decreased 2.8% per year on average, but improvements have slackened over time.

B. Technologies for Reducing Transportation Sector Emissions

We summarize below two types of cutting-edge technologies with significant potential to achieve emissions reductions in the transportation sector: (1) weight-reducing advanced materials technologies; and (2) additive manufacturing (3D printing) technologies.

The technologies and companies such as those that we identify below may assist companies to address the emissions reduction goals that EPA suggests for this sector, which include fuel switching (use of alternative fuel sources including: biofuels; hydrogen; wind and solar electricity; and less carbon-intensive fossil fuels) and fuel efficiency (improving fuel efficiency with advanced technologies, design, and materials in the development of more fuel-efficient vehicles), as well as more fuel efficient operating practices and the reduction in travel demand.

1. Weight-Reducing Advanced Materials Technologies

Weight-reducing advanced materials drive innovation in material efficiency – the general term for producing the same set of products with less material – by "lightweighting," or reducing a product's mass to reduce its in-use energy consumption.[177] Vehicles are a natural target for lightweighting, where materials such as steel can be replaced with aluminum, carbon fiber, or other strong, lightweight materials to increase vehicle fuel efficiency. Although production of such advanced materials themselves may be emissions-intensive relative to the conventional materials in vehicles that they would replace, studies show that energy savings and emissions reductions achieved through advanced materials over the lifetime of lightweight vehicles are, on balance, greater than the extra energy and emissions associated with manufacturing the advanced materials. A 10% reduction in vehicle weight can result in a 6%–8% fuel economy improvement, whereas some combinations of advanced materials can reduce the weight of a vehicle's body and chassis by up to 50%, achieving more significant emissions reductions.[178]

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[175] IEA, Trucks and Buses Tracking Report – June 2020, https://www.iea.org/reports/trucks-and-buses.

[176] IEA, Aviation Tracking Report – June 2020, https://www.iea.org/reports/aviation.

[177] Rissman, et al., Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070, Applied Energy Vol. 266, at 17 (2020), https://energyinnovation.org/wp-content/uploads/2020/04/Technologies-and-policies-to-decarbonize-global-industry-review-and-assessment-of-mitigation-drivers-through-2070.pdf.

[178] US Dept. of Energy, Office of Energy Efficiency and Renewable Energy, Vehicle Technologies Office, Lightweight Materials for Cars and Trucks, https://www.energy.gov/eere/vehicles/lightweight-materials-cars-and-trucks.

Given that transportation accounts for nearly a third of GHG emissions in the United States, a 10% to 30% reduction in the weight of an automobile or aircraft could materially reduce aggregate GHG emissions.[179]

Advanced materials manufacturing has already been achieved in practice, but has not been commercialized to the same extent as the other technologies discussed herein. There is an opportunity to accelerate advanced materials commercialization through further research and development to achieve greater market penetration and economies of scale.[180] Although scientists have gained ground in understanding the properties of advanced materials such as magnesium, carbon fiber composites, aluminum and aluminum matrix composites, titanium, glass fiber composites, and advanced high-strength steel, and companies are already manufacturing these materials, additional research would help lower the cost of production and improve related manufacturing processes for joining, modeling, and recycling the materials.[181]

2. Additive Manufacturing (3D Printing Technologies)

Additive manufacturing is the process of manufacturing a product by starting with a material and constructing the product layer by layer. This term can refer to any process by which an object is created in this manner, including, for example, through molding, but typically refers to "3D Printing." Additive manufacturing has the potential to make the supply chain significantly more efficient, reducing the need for transportation of finished goods across oceans or countries to get them to market.

Additive manufacturing has a number of other advantages over conventional manufacturing. Additive manufacturing can eliminate intermediate steps in the supply chain, because manufacturers can create a part with their own computer and a printer. Additive manufacturing also allows for easier creation of objects that are "functionally-graded," i.e., objects that have different interior and exterior materials depending on product requirements. Finally, additive manufacturing is more conducive to creating objects with complex geometries, which allows for the production of lighter parts and components in smaller lot sizes. With conventional manufacturing, the mass production of these types of parts is typically only economical if produced in high volumes. Additive manufacturing has substantial advantages in producing products for which functionality and small lot sizes are important.

Additive manufacturing technologies have been achieved in practice but not at all scales. As of 2019, the world's largest 3D Printer (polymer) was capable of producing objects up to 100 feet long, 20 feet wide, and 10 feet tall, and set a world record in printing a 25-foot, 5,000-pound patrol boat in just 72 hours.[182] The next largest 3D Printer in use is six times

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[179] *See* US EPA, *Carbon Pollution from Transportation*, https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation#:~:text=%E2%80%8BGreenhouse%20gas%20(GHG)%20emissions,terms%20than%20any%20other%20sector.

[180] *See id.*

[181] *See id.*

[182] *The first 3D-printed boat, 'built' by the world's largest 3D printer*, CNBC.COM (Oct. 11, 2019), available at: https://www.cnbc.com/video/2019/10/11/the-first-3d-printed-boat-built-by-the-worlds-largest-3d-printer.html.

smaller. There remain, however, a number of challenges in scaling additive manufacturing – for example, additive manufacturing processes are relatively inefficient at mass production and currently lack uniform product or industry standards.[183]

The significance of further expansion of additive manufacturing on US economic competitiveness cannot be overestimated. The manufacturing sector is the fifth largest employment sector in the United States.[184] America leads the world in metallurgy, and support for additive manufacturing aids this large base of employment potential not just by making materials more competitive, but also by providing advantages to other industries by making parts and components more widely and locally available. The ability to fabricate parts and components at a higher level of detail and customization enables stronger, lighter, better designed, and less costly automobiles, trucks, and planes, making those industries more globally competitive and their manufacturing processes more efficient and less wasteful.[185]

Similarly, additive manufacturing could substantially reduce the amount of GHGs emitted in the supply chain, as more than 45 billion ton-miles of transportation equipment are moved each year in the United States.[186] Harnessing the power of additive manufacturing to disrupt and streamline the supply chain could be a game-changer in reducing transportation-related greenhouse gas emissions. One recent study found that additive manufacturing has the potential to reduce global energy demand by between 5% and 27%, taking into account reductions in transportation, material savings, and other benefits.[187]

C. Example Companies: Harder and Stronger Metals from Veloxint and NanoAl and 3D Printed Metal Parts from Desktop Metal and ExOne

We provide overviews below of four companies at the cutting edge of emissions reduction technology in the transportation sector: two in the category of enhancing weight-related energy efficiency for cars, trucks, and planes through the use of advanced materials (Veloxint CIF and NanoAL); and two in the category of reducing emissions from goods movement by localizing manufacturing with 3D printers (Desktop Metal and ExOne).

1. Veloxint CIF

Veloxint CIF is an MIT-incubated startup company based in Framingham,

[183] AMFG, *10 of the Biggest Challenges in Scaling Additive Manufacturing for Production in 2020 [Expert Roundup]* (Oct. 10, 2019), https://amfg.ai/2019/10/08/10-of-the-biggest-challenges-in-scaling-additive-manufacturing-for-production-expert-roundup/.

[184] A. Grundy, *Contributions of Key Economic Sector Recognized on Manufacturing Day*, CENSUS.GOV (Oct. 2, 2020), https://www.census.gov/library/stories/2020/10/manufacturing-still-among-top-five-united-states-employers.html.

[185] *See, e.g.*, R. D'Aveni, *The 3-D Printing Revolution*, HARVARD BUSINESS REVIEW (May 2015), available at: https://hbr.org/2015/05/the-3-d-printing-revolution.

[186] D.S. Thomas & S.W. Gilbert, US Dep't of Commerce, *National Institute of Standards and Technology*, *Costs and Cost Effectiveness of Additive Manufacturing*, NIST SPECIAL PUBLICATION 1176 (Dec. 2014), available at: http://dx.doi.org/10.6028/NIST.SP.1176.

[187] *See* The effect of additive manufacturing on global energy demand: an assessment using a bottom-up approach, Leendert, Energy Policy 112 (2018).

Massachusetts, that has developed a method invented at MIT to make nanocrystalline metal alloys.[188] Strength is well-known to be inversely proportional to the size of the metallic structure (crystal size). The smaller the crystals, the harder and stronger the metal. Professor Christopher Schuh, head of the Department of Materials Science and Engineering at MIT, invented a process that generates nanometric-sized crystals (about 10 times smaller than the crystallinity of conventional metals). This invention has enabled alloy designs that are up to three times harder and stronger than any metal previously made. Veloxint harnesses this method to offer the potential to use one-third the amount of metal for a given part, thereby lightweighting automobiles and planes, reducing fuel consumption, and reducing GHG emissions.

In February 2020, Veloxint was awarded a three-year grant by the US Department of Energy's Advanced Manufacturing Office under the category of Innovations for the Manufacture of Advanced Materials, which will pair Veloxint with a world-class industrial-government-academic team, including experts at GE Research, Oak Ridge National Laboratory, and the University of Kentucky, to develop and scale next-generation nanocrystalline metal alloys via advanced manufacturing processes.[189]

On March 17, 2021, ARC Group Worldwide, Inc. announced, in conjunction with its majority shareholder Quadrant Management, that they entered into an ownership investment into Veloxint to enhance the development and commercialization of Veloxint's nanocrystalline metal alloy materials.[190]

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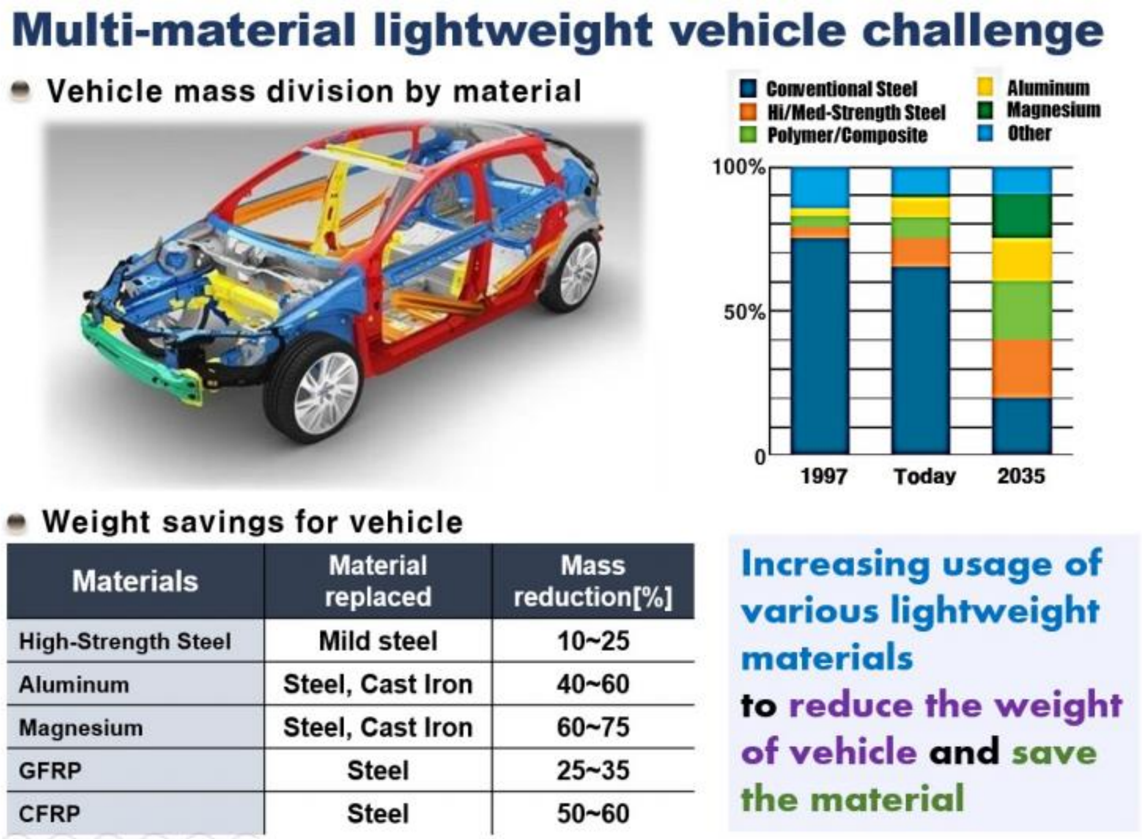
[188] www.veloxintcif.com

[189] Veloxint Selected for Department of Energy Grant to Accelerate Innovation in the Manufacture of Advanced Nanocrystalline Metal Alloys, *Business Wire* (Feb. 25, 2020), https://www.businesswire.com/news/home/20200225005291/en/Veloxint-Selected-Depa%E2%80%A6.

[190] ARC Group Worldwide Announces Investment in Veloxint CIF, *Yahoo! Finance* (Mar. 17, 2021), https://finance.yahoo.com/news/arc-group-worldwide-announces-investment-160000839.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAFfy3klXgXH29rtAoDS1EnNIx-HkU2zQryN11mPT7jO_dwUPo8or62gnGZI_u8UxPAUrAmPbXr7sN2j9fRIhbejKb7RgBNdtHSY0-Ugn7a4AnFCbTj0ykD8nOnUKgEKbLVUPm8DpRV1Z5h9sRZ5N80RaxVKPMS4HWAW3HN9uXu4J.



__A presentation from Tata Steel shows the potential for lightweighting of motor vehicles through the use of advanced materials__.[191]

2. NanoAL

NanoAL is a materials research and technology company based in Ashland, Massachusetts, dedicated to design, development, and commercialization of high-performance aluminum alloys based on scientifically-designed nanostructures.[192] NanoAL has developed alloys that typically exhibit increased strength performance by 20%–60% over incumbent aluminum alloys while also increasing the operating temperature range of aluminum. The company has achieved these performance benefits by employing a technology that controls nano-scale microcrystalline structures in its aluminum alloys using 100% pre-alloyed compositions and simple thermal treatments.

These innovations enable the replacement of heavier metals such as steel and titanium with significantly lighter aluminum while maintaining the necessary performance. Target applications for automobiles and planes result in significant reductions in weight (lightweighting). As an example of a practical application of NanoAL's technology, the company states that replacing just the brake discs on a car using these methods could reduce the

[191] Tata Steel, Beyond material comparison to holistic engineered material solutions, presentation to ICTP 2017, available at: http://www.ictp2017.org/sites/www.ictp2017.org/files/iw1-slides_0.pdf (last visited May 2, 2021).

[192] www.nanoal.com.

car's weight by 40 pounds. NanoAL's heat-treatable alloys also can be used for casting, wire and sheet forming, extrusion into bar or rod, and as powders for additive manufacturing.

NanoAL has received numerous awards and contracts from small and large industrial partners as well as the Department of Energy, the Department of Defense, and the National Science Foundation. NanoAL continues to serve clients in US governmental agencies and Fortune 500 companies. NanoAL LLC was acquired by Unity Aluminum in September 2018 to form the core research group for new aluminum alloys, allowing the company to use its growing team and resources to continue its work on accelerating the commercialization of NanoAL technologies.

On February 22, 2021, NanoAL signed a long-term commercial license agreement for advanced aluminum alloy products with Mitsubishi Corporation RTM Japan. The agreement will enable NanoAL to bring its Addalloy® family of advanced aluminum alloy powders into the Metal Additive Manufacturing (AM) Market in Asia. NanoAL and Mitsubishi also signed a letter of intent for potential partnerships on additional NanoAL advanced aluminum alloy products, including aluminum casting and rolled sheets for automotive and other industrial applications.[193]

3. Desktop Metal

Desktop Metal seeks to make "3D printing accessible to all Engineers, Designers, and Manufacturers."[194] It describes its core technology as "microwave enhanced sintering," where layers of metal and ceramic powders are laid down, mixed in a soft polymer, and then placed in a furnace where it is rapidly cooked and the polymer is burned off.[195]

With this technology, Desktop Metal has designed and launched 3D printing systems specialized for different types and stages of the manufacturing process. Its first two products were launched in 2017. The Studio System is a counter-top model designed for an office for use by engineers and small production runs.[196] The Production System is a larger model intended for use by manufacturers and large-scale, high volume production, using "Single Pass Jetting technology and bi-directional printing to achieve speeds up to 100 times those of laser powder bed fusion technologies."[197] In 2019, Desktop Metal launched two additional systems: the Shop System, designed for machine shops; and Fiber, a continuous carbon fiber printer using

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[193] NanoAL Signs a Long-Term Commercial License Agreement for Advanced Aluminum Alloy Products with Mitsubishi Corporation RTM Japan, NanoAL (Feb. 22, 2021), https://www.nanoal.com/nanoal-mitsubishi-announcement.

[194] Desktop Metal, About Us, available at: https://www.desktopmetal.com/about-us.

[195] Techcrunch, Desktop Metal reveals how its 3D printers rapidly churn out metal objects (April 25, 2017), available at: https://techcrunch.com/2017/04/25/desktop-metal-reveals-how-its-3d-printers-rapidly-churn-out-metal-objects/

[196] Desktop Metal, Studio System, available at: https://www.desktopmetal.com/products/studio

[197] Desktop Metal, Production System, available at: https://www.desktopmetal.com/products/production

automated fiber placement technology to produce high-performance parts for use in aerospace and industrial-grade applications.[198]

Desktop Metal has also developed products in the software as a service ("SaaS") space: "Live Parts" is an AI software program that debuted in 2018 to allow users to input specifications for an object and create it from any 3D printing system.

Desktop Metal has received venture funding from GV (Google Ventures), BMW, and Ford Motor Company, among others, and its earliest customers include Google, United States Navy, Built-Rite Tool & Die, and Lumenium.

As of 2018, Desktop Metal was tied for first among US tech start-ups that achieved $1 billion valuations (one year, nine months).[199] In late 2020, Desktop Metal went public through a reverse merger with Trine Acquisition in a deal that valued Desktop Metal at $2.5 billion. Desktop Metal now trades on the NYSE under "DM" with a market capitalization of approximately $3.24 billion as of April 2021.

Desktop Metal was founded in 2015 in Cambridge, Massachusetts, and is currently headquartered in nearby Burlington, Massachusetts.

[200]

<u>Desktop Metal printers</u>

[198] Desktop Metal, Fiber and Shop System, available at https://www.desktopmetal.com/products/fiber and https://www.desktopmetal.com/products/shop

[199] J. Schwartz, *Fastest Unicorns Have the Best Track Records and Money*, BARRONS.COM (May 11, 2018), available at: https://www.barrons.com/articles/fastest-unicorns-have-the-best-track-records-and-money-1526071397.

[200] Source: Desktop Metal

4. ExOne

ExOne specializes in binder jetting technology for 3D printing for industrial uses, which it has dubbed the "ExOne® process."[201] ExOne describes its binder jetting process as one in which "an industrial printhead selectively deposits a liquid binding agent onto a thin layer of powder particles – either metal, sand, ceramics, or composites – to build high-value and one-of-a-kind parts and tooling. The process is repeated layer by layer, using a map from a digital design file, until the object is complete."[202]

ExOne began in 1995 as a division of Extrude Hone, which was a machining and automation systems company based in Irwin, Pennsylvania. Extrude Hone started manufacturing 3D printing systems in 1998, and, in 2002, ExOne launched with three new 3D printing systems over the next three years: the R2 metal 3D printer, for use in production and research applications; the X1-Lab, for use primarily in the dental industry for the production of crowns and bridges; and the S-Print, for use as a sand printer in the foundry market.[203] Since 2019, ExOne has introduced more than a dozen 3D printers for metal, sand, ceramic, and composite materials. Roughly half of ExOne machines installed are used to 3D print molds and cores for metal casting, with the remainder used to print metal, ceramics, and composite parts.

Recently, ExOne has entered into a variety of strategic partnerships or joint ventures with other companies in the manufacturing space, including Rapidia (a Vancouver, Canada-based technology company), Siemens (an automation and digitalization technology company), and Ford Motor Company. One of ExOne's earliest customers was Motorola.

ExOne went public in 2013 and trades under "XONE" with a market capitalization of approximately $531 million as of April 2021. In August 2021, Desktop Metal announced the planned acquisition of ExOne.[204]

ExOne is currently headquartered in North Huntingdon, Pennsylvania, and its North American Research Facility is in St. Clairsville, Ohio. ExOne also has locations in Mexico and across Europe and Asia.

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[201] https://www.exone.com/

[202] ExOne, *What is Binder Jetting?*, https://www.exone.com/en-US/case-studies/what-is-binder-jetting.

[203] ExOne, Our Story, https://www.exone.com/cmsctx/pv/kkilgore/culture/en-US/wg/6f719caf-ff5d-4607-86f2-4237bac4a653/readonly/0/ea/1/h/2ceefaaea9dd02fcbacdbbcc65568f3236d5d77c9b949bde3e744b1e98011353/-/en-US/About/Our-Story?uh=72b1ecab8333a4e8ca87e8aa93c061c99cc04b7bca6fa978b8fe5b8fd9ad95f2.

[204] Desktop Metal, Desktop Metal to Acquire ExOne, Cementing Its Leadership in Additive Manufacturing for Mass Production (August 11, 2021), available at: https://ir.desktopmetal.com/news/press-releases/detail/68/desktop-metal-to-acquire-exone-cementing-its-leadership-in.

Afterword

This report has shown that there are significant opportunities to reduce greenhouse gas emissions from key areas of the economy – the buildings sector, materials, and oil and natural gas production – with emerging and scalable-ready technologies.

Improving building construction and operation can deliver lasting emission reduction benefits. Buildings last a long time. So we need to make sure that new buildings are built to operate as efficiently as possible because the consequences will be felt for decades. We have shown here how selecting the right windows, implementing smart controls, and harnessing geothermal energy can transform buildings so they can both operate with less energy and generate their own. Modular building technology can make new buildings more energy efficient and reduce time and materials in construction, thereby saving energy and reducing greenhouse gas emissions in the construction process. For existing buildings, some of the same technologies can be deployed, but also technologies for sealing leaks, filtering air, and making buildings smarter can reduce energy use in the massive existing building stock.

We are excited about the emission-reducing opportunities this report presents for the illustrated materials. Carbon capture in the cement process and a new pozzolanic cement manufacturing process offer exceptionally significant opportunities to reduce the cement industry's carbon footprint. Likewise, while electrifying vehicle propulsion will transform the transportation sector's footprint, the advanced materials showcased in this report can significantly reduce energy use by minimizing vehicle weight without sacrificing payload and performance. As we have indicated, the potential for innovations in the materials sector to reduce emissions often gets overlooked, and technologies presented in this backgrounder can significantly reduce the outsized impact that cement has on global emissions, as well as make vehicles lighter and safer to improve performance of electric vehicles.

And, finally, we have highlighted a relatively easy fix for reducing methane leaks from oil and natural gas production, an area already prioritized by the Administration and EPA's forthcoming methane rulemaking.

Elevating the visibility of these sectors and technologies is a good first step in helping to get these and other solutions deployed. But visibility will not be enough. Part Two of our joint Earthshot™/ASU showcase, to be scheduled in early 2022, will focus on strategies to accelerate technology deployment. How can we ensure that these exciting new technologies will thrive? We look forward to discussing the full range of possible tools, including policy instruments at all levels of government, public, and private finance and procurement, benchmarking, and education.

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